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**VOLUNTARY PHYSICAL ACTIVITY: MEASUREMENT AND
RELATIONSHIP TO SELECTED HEALTH PARAMETERS IN
RURAL BLACK SOUTH AFRICANS RESIDENT IN THE
LIMPOPO PROVINCE, SOUTH AFRICA**

by

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Thesis presented for the Degree of
DOCTOR OF PHILOSOPHY
in the Department of Human Biology
UNIVERSITY OF CAPE TOWN
South Africa

November 2012

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Dedicated to my father

Kenneth Weston Cook (1936 – 2011)

"There is a time for everything, and a season for every activity under heaven"

Ecclesiastes 3: 1

"Whatever your hand finds to do, do it with all your might..."

Ecclesiastes 9: 10

"...Of making many books there is no end, and much study wearies the body"

Ecclesiastes 12: 12

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ACKNOWLEDGEMENTS

Vicki Lambert

These few words do not do justice to the patience and understanding, guidance and inspiration, insightful comment and continual encouragement that you have provided. Thank you for your courage and trust in allowing me the freedom to wander off into the unknown, yet the honesty to keep me on track. The independence I have gained and all that I have learnt from this journey is of inestimable value: thank you so much!

Marianne Alberts

Your energy and enthusiasm, work ethic and integrity, and generosity and trust have made this journey possible. Many thanks for introducing me to, and allowing me to work in the communities in Dikgale, and for all the wonderful opportunities and people I've been able to experience and learn from. I am deeply indebted.

Work colleagues

To my colleagues and friends Sanette Brits and Las du Plessis, I am deeply thankful and forever grateful for your being there as trusted advisors and confidants during this period. My sincere thanks to Professor D Wessels, Professor M Themane and Dr MA Rampedi, for allowing me the time, space and resources to pursue my passion.

Family and friends

To my wife Ingrid and daughter Shannon; it is done! Thank you from the bottom of my heart! To my parents, Ken and Stienie, your sacrifices and continual encouragement are deeply etched in my heart. To my sister, Glynnis, you have been a pillar I could lean on and are indeed a great blessing to me. To my friends, Rob Ayliffe in particular, thanks for keeping me grounded during this period.

The research undertaken in this PhD thesis was funded in part by the University of Limpopo (Turfloop Campus), the University of Cape Town, the National Research Foundation of South Africa and the Medical Research Council of South Africa.

DECLARATION

I, Ian Cook, do hereby declare that the research presented in this thesis is my own unaided work, both in concept and execution, and apart from the normal guidance from my supervisors I have received no other assistance. Neither the substance nor any part of this thesis has been submitted in the past, or is being, or is to be submitted for a degree in this or any other University.

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This thesis is presented for examination in fulfilment of the requirements for the degree of Doctor of Philosophy.

Signature: _____

Date: _____

ACADEMIC PUBLICATIONS

Relationship between adiposity and pedometer-assessed ambulatory activity in adult, rural African women. Cook I, Alberts M, Lambert EV. *International Journal of Obesity* 32: 1327-1330, 2008.

Sources of variance and reliability of objectively monitored physical activity in rural and urban Northern Sotho-speaking blacks. Cook I, Lambert EV. *South African Journal of Sports Medicine* 20(1): 21-27, 2008.

Monitor placement, sources of variance and reliability of free-living physical activity – a pilot investigation. Cook I, Lambert EV. *South African Journal of Sports Medicine* 21(1): 16-21, 2009.

Development of a four-item physical activity index from information about subsistence living in rural african women. A descriptive, cross-sectional investigation. Cook I, Alberts M, Lambert EV. *International Journal of Behavioral Nutrition and Physical Activity* 6:75, 2009.

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Effect of body mass and physical activity volume and Intensity on pedometry-measured activity energy expenditure in rural, black South Africans in the Limpopo Province. Cook I, Alberts M, Lambert EV. *South African Journal of Sports Medicine* 22(1): 3-7, 2010.

Compliance with physical activity guidelines in rural, black South Africans in the Limpopo Province: an energy expenditure approach. Cook I, Alberts M, Lambert EV. *British Journal of Sports Medicine* 45: 619-625, 2011.

Patterns and volumes of accelerometry-measured physical activity in rural and urban black South African females in the Limpopo Province, South Africa. Cook I, Alberts M, Lambert EV. *Journal of Physical Activity and Health* 9: 300-310, 2012.

CONFERENCE PRESENTATIONS

Accelerometry as a measure of physical activity in free-living humans: a useful tool in climate research. UJ/MRC/WHO Public Seminar: Living in a warmer world: what it may mean for sun-exposed South African workers? 19th August 2011, University of Johannesburg, Gauteng, South Africa.

University of Cape Town

THESIS ABSTRACT

The use of objective measures of physical activity in addition to, or in place of, subjective or self-report measures of physical activity, is being increasingly promoted in Physical Activity Epidemiology research. This thesis investigates methodological issues related to the use of objective measures of physical activity and presents pioneering objectively measured physical activity survey results from a rural South African setting. In this series of studies, we firstly explored the sources of variance in the objective measure of physical activity (uni-axial accelerometer) as a function of residence and also movement monitor placement. Secondly, we highlighted the importance of Non-Exercise Activity Thermogenesis (NEAT) in a rural African setting and the importance of considering the full spectrum of accelerometer counts when contrasting rural and urban populations. Thirdly, we demonstrated novel approaches to pedometry data from a rural African setting, such that volume-intensity effects could be inferred, and using estimated energy expenditure whether current physical activity guidelines are met. Finally, we identified that the current recommendations for physical activity and health, applied in a rural African setting, may miss important and possible health-promoting physical activity.

In Chapter 2 the sources of variance and reliability using uni-axial accelerometry for a 14-hr and 4-day monitoring period in 41 rural and urban adult, black South Africans are investigated. For the 14-hr monitoring period variance was distributed as follows: inter-individual (3-18%), intra-individual (71-82%), and hr-of-day (2-14%). Variance for the 4-day monitoring period differed from the 14-hr monitoring period: inter-individual (47-58%), intra-individual (43-51%) and day-of-wk (0-6.5%). Irrespective of the monitoring period, total counts, average counts and moderate-to-vigorous activity tended to be the most reliable measures requiring the fewest number of monitoring periods. These findings provide an insight for understanding how variance is distributed in objectively measured activity patterns of a South African sample and show that reliable measures of adult physical activity behaviours require 18-128 hr and 3-44 days, depending on the monitoring period, residence status and gender.

An important aspect to consider when using movement monitors is the effect of monitor placement on the sources of variance and reliability of objectively measured free-living physical activity. Seven rural, black South Africans wore uni-axial accelerometers on both hips. Accelerometer output did not differ across trials for either hip placement ($p>0.2$). There were no significant differences between hips for any accelerometer variable ($p>0.1$) and effect sizes were small. Monitor position did not contribute any variance to accelerometer variables. Variance due to monitor unit contributed $<2\%$ to raw and derived accelerometer variables. Intraclass correlation coefficients were >0.80 for all accelerometer-derived indices. The most important finding in Chapter 3, in contrast to findings from more industrialised settings, is the greater variability in monitor placement for certain moderate-to-vigorous accelerometer variables.

The importance of NEAT in rural African settings needs to be emphasized. In Chapter 4 the criterion validity of a Subsistence Activity Index derived from socio-demographic variables, which broadly represent NEAT categories from two datasets of rural African women ($n=138$, $n=206$) is established. A three-point physical activity subsistence-based index was constructed from four socio-demographic questions related to electricity, cooking methods, water collection and availability of motorized transport. Age, educational level and health status were not related to the subsistence index ($p>0.1$). There was a significant negative, linear trend between the subsistence index and adiposity level ($p<0.04$) and fasting blood glucose concentration ($p<0.0001$). In contrast, there was a significant positive, linear trend for accelerometry output and fitness across subsistence index levels ($p<0.03$). This study demonstrates the importance of considering NEAT in these rural settings and provides a validated Subsistence Activity Index for broadly categorizing levels of physical activity in this specific population of rural African women.

In Chapter 5 the effect of two different uni-axial accelerometer cutpoints or intensity thresholds on physical activity patterns in rural ($n=263$) and urban ($n=16$) black South African women over a average 20-hr period is reported. Total counts and average counts were higher ($p<0.01$), sedentary time lower ($p=0.0042$), and moderate-to-vigorous variables ($p\leq 0.0179$) in rural women compared with urban

women. Estimated adherence (bouts ≥ 10 min, ≥ 30 min.day⁻¹ for 5 days.wk⁻¹) was 1.4-fold higher in rural women than urban women for counts ≥ 760 , but 3.3-fold higher in urban women than rural women for counts ≥ 1952 . This novel study presents evidence that rural women accumulate greater amounts of physical activity than urban women within a particular count band and that depending on which moderate physical activity intensity threshold is used to estimate physical activity guideline adherence, rural women could be classified as less physically active than urban women.

The sixth study investigates the association between adiposity and 7-day ambulation levels using a coiled-sprung electronic pedometer in 121 adult, rural black South African women. Sedentarism (< 5000 steps.day⁻¹) was found in 13.7%, while 39.7% were classified as accruing sufficient physical activity (≥ 10000 steps.day⁻¹). After adjusting for age, only body mass index remained significantly associated with steps.day⁻¹ ($p=0.032$). After multivariate adjustment body mass index decreased 1.4 kg.m⁻² per 5000 steps.day⁻¹ ($p=0.035$), access to a motor vehicle within the household increased percentage body fat by 4% ($p=0.018$), and compared with sedentarism the risk of obesity was 52% lower at 10 000 steps.day⁻¹ ($p=0.028$). This study found associations between active and passive transport modalities and adiposity, and also provided important practical insights into using a coiled-sprung research-grade pedometer in a rural African setting.

Following on from the sixth study, a multi-day memory, accelerometer-based pedometer was used to record ambulation levels in 789 rural black South Africans over seven days. The multivariate-adjusted seven-day ambulation level was 12 471 steps.day⁻¹. The ambulation levels differed between sexes and weekday ambulation differed from weekend ambulation ($p<0.03$). Prevalences, age-adjusted to the world population, for < 5000 steps.day⁻¹, 5000-9999 steps.day⁻¹ and ≥ 10000 steps.day⁻¹ were 8.0%, 25.5% and 66.6%, respectively. After multivariate adjustment, adiposity measures were significantly associated with steps.day⁻¹, and < 5000 steps.day⁻¹ increased the risk of obesity by more than two-fold, compared with ≥ 10000 steps.day⁻¹ ($p<0.05$). Achieving $< 10\ 000$ steps.day⁻¹ compared with $\geq 10\ 000$ steps.day⁻¹, was associated with an increased multivariate-adjusted obesity risk of

86-89% ($p<0.001$). This study demonstrated the feasibility of using an objective measure of physical activity in a relatively large sample, in a rural African setting, and the advantages of using accelerometer-based technology. The study also highlighted the high ambulation levels in this rural African sample and thus the importance of walking as a mode of transport. At present, walking constitutes a large proportion of daily NEAT in this community in transition.

Chapters 8 and 9 report novel analytical approaches to the pedometry data collected in Chapter 7. Pedometry data is usually expressed as steps per day and provides no indication of the intensity. Consequently, although pedometry is a valid and reliable measure of ambulatory activity, it is problematic when attempting to reconcile the standard step output to physical activity guidelines. In Chapter 8, a novel statistical approach, using variance components and general linear models, is explored for investigating whether total weekly ambulation activity energy expenditure in rural black South Africans was primarily explained by volume or by intensity. Body mass, intensity and volume explained >90% of the variance in activity energy expenditure. Adjusted activity energy expenditure did not differ between sexes or across activity categories ($p>0.1$). In contrast, adjusted activity energy expenditure for 6-7 days of compliance ($\geq 10\,000$ steps.day⁻¹) differed significantly from 1-2 days of compliance ($p<0.04$). This study highlighted a possible intensity effect for 6-7 days of compliance and at high ambulatory levels ($\geq 12\,500$ steps.day⁻¹) while a volume effect appeared to dominate between sexes, across activity categories and weight-by-activity categories.

Finally, in Chapter 9 a novel energy expenditure-based approach to pedometry data is used to examine non-compliance or compliance¹ with physical activity guidelines in rural, black South Africans. The age and sex adjusted prevalence for non-compliance, American College of Sports Medicine (ACSM) compliance and Institute of Medicine (IOM) compliance in the sample was 7.8%, 55.0% and 37.2%,

¹ For the sake of brevity the convention in this thesis is that non-compliance / compliance or non-adherence / adherence refers to not meeting or meeting recommendations for physical activity, based on current guidelines

respectively. Complying with IOM guidelines required substantially more ambulation (14 522 steps.day⁻¹) than ACSM guidelines (10 837 steps.day⁻¹) and non-compliance (6420 steps.day⁻¹) ($p<0.0001$). Compliance with physical activity guidelines was associated with a 49-87% ($p<0.07$) reduced risk of obesity, while partial and full IOM compliance was associated with a 42-74% reduced risk of obesity ($p<0.04$). This study demonstrates the utility of using the concurrent activity energy expenditure and step data to infer compliance with physical activity guidelines, and the average steps per day required to comply with the physical activity guidelines.

In conclusion this thesis found that while some methodological aspects such as variance distribution and the number of days required for reliable estimation of objectively measured physical activity are in general agreement with findings from more industrialised settings, aspects related to pedometer mechanism, monitor placement and cut-point selection should be carefully considered when implementing objective measures in a rural setting. These methodological differences are related to the predominance of NEAT within these rural African settings. The novel use of pedometer data has demonstrated that this type of data can be more directly reconciled with physical activity guidelines than is currently the case. In contrast with self-report survey results both locally and nationally, the data suggests that rural black South Africans are more physically active than is currently estimated primarily because of the large volume of accumulated NEAT which is not probed with current self-report, surveillance measures. Further research is required to develop a more robust and sensitive self-report system for use in rural communities where NEAT is being rapidly eroded. It is recommended that the greater implementation of objective measures of physical activity in rural settings should be pursued both in terms of stand-alone surveys and within surveys that employ both subjective and objective measures of physical activity. This will provide for a more accurate and richer description of physical activity patterns and volumes in rural South African settings, and the ability to attenuate the relationship between physical activity and health outcomes.

CHAPTER 1: LITERATURE REVIEW

1.1. INTRODUCTION

Physical Activity Epidemiology, defined as the study of “*factors associated with participation in a specific behaviour – that is, physical activity – and how this behaviour relates to the probability of disease or injury*”,¹⁶¹ has developed as a relatively new branch in the general field of Epidemiology (*the study of the distribution and determinants of health-related states and events in a population*).¹⁶¹

The origin of epidemiological research can be dated back to the seminal work of John Snow regarding the outbreak of cholera in London, 1849⁶⁸ while the origins of Physical Activity Epidemiology are far more recent.¹⁶¹ Evidence linking physical activity to health in Africa dates back to Ancient Egypt (2687–2191 BC).⁶⁹² During the late 1940's Jeremy N Morris started investigating the effect of sedentary and physically demanding occupations in England on cardiovascular disease. During the 1960's Ralph S Paffenbarger initiated similarly ground-breaking research in the United States of America into the effect of work, transport and leisure physical activity (PA) on health and longevity. Consequently, through the 1950's and into the 1970's, Morris and Paffenbarger published a number of pioneering studies on Harvard Alumni, San Francisco longshoresman, London bus drivers and conductors, and British civil servants which laid the foundation for using epidemiological methods to investigate the relationship between PA, morbidity and mortality.^{464,467} During the early 1990's Steven N Blair extended Physical Activity Epidemiology by studying the association between cardiorespiratory physical fitness and all-cause mortality using longitudinal data from the Aerobics Centre Longitudinal Study.^{70,71} Despite the impressive evidence amassed by Morris, Paffenbarger, Blair and others,¹⁶¹ it was only in 1992 that the American Heart Association formally recognized physical inactivity (PI) as an independent risk factor for coronary artery disease.²⁰⁶ In fact, Caspersen stated that PI was as important a risk factor as elevated serum cholesterol, smoking and hypertension¹⁰⁷ and recent data from China concurs, reporting equivalent risks for PI and cigarette smoking.²⁶² However, the lag of ≈40 yr between the evidence that PA improves health and longevity, and policy is certainly an improvement on the more than 200 year lag between the evidence that citrus fruits prevent scurvy and the implementation of policy!⁴⁷⁹ The quantity and quality of

data collected in the field of Physical Activity Epidemiology, primarily within Established Market Economies (EME), has accumulated to the extent that a number of excellent reviews^{52,108,465,466} and texts^{26,86,87,161,253,261,279,342,352} detail the evidence that has allowed a causal relationship to be confidently established between PA and health.

Compared with international research endeavours, work within South Africa in the area of Physical Activity Epidemiology only commenced in the early 1980's and until the 1990's relatively few published reports have emanated from South Africa.^{450,527,558,569,571,572} Early work by South African researchers noted qualitatively that rural Africans were physically active but no attempts were made to quantify this.^{644,646} Since 2000 it would appear that work in the area of Physical Activity Epidemiology in South Africa has accelerated and has probably been driven by at least three significant developments in Physical Activity Epidemiology namely,

- accumulating evidence of the importance of addressing PI as a risk factor for poor health even within Developing Regions,^{50,52,209}
- the Global Burden of Disease Study (GBD, 1990-2004),^{103,437} the INTERHEART Study (1999-2003),⁵⁷⁴ the World Health Survey (2002-2003),²⁴⁰ the First South African National Youth Risk Behaviour Study (2002),^{19,517} and the South African Demographic and Health Survey (SADHS, 2003)¹⁵⁶ all of which included PI as a risk factor,
- the international collaborative effort to validate the International Physical Activity Questionnaire (IPAQ, 1998-2000)¹⁴¹ and the Global Physical Activity Questionnaire (GPAQ, 2002-2004).^{27,104}

The lack of Physical Activity Epidemiology evidence from a South African perspective has been noted,⁴⁵¹ as has the improvement in the quantity of Physical Activity Epidemiology evidence from 1995 to 2005.³³² However, still lacking until relatively recently, has been the use of objective measures of physical activity within the African and regional (Sub-Saharan Africa, SSA) setting,^{29-31,58,59,119,171,269,554} the South African setting,^{78,168-170,331,334} and in particular the rural South African setting.¹³⁶

Similarly, Physical Activity Epidemiology evidence from the perspective of Developing Market Economies (DME) is sparse and only recently has an attempt been made to document the quantity and quality of the evidence.⁶⁸⁵ However, the strength of the evidence has been weakened because too few published studies have relied on properly and rigorously validated physical activity questionnaires (PAQ). For instance, the GBD 2004¹⁰³ included results from the South African BRISK Study⁵⁶⁹ which used a PAQ which has not been properly evaluated for validity and reliability.¹³⁰ This has been problematic when applying PAQ in more demanding situations such as rural settings where conceptual understandings of aspects such as leisure and exercise are relatively unknown because of the greater amount of time spent in subsistence activities.⁵⁹⁴ Moreover, technological advances have made it possible to seriously consider the use of objectively-measured PA in population based surveys,^{126,393,605,623} which should prove useful especially in situations where the implementation of self-report PA might be challenging.

Consequently, this review will first briefly discuss the Chronic Diseases of Lifestyle (CDL) epidemic from an international, regional and national perspective. Second, PI as a primary risk factor for CDL will be placed within the CDL epidemic. How Physical Activity Epidemiology might differ between Developed and Developing Countries, and the possible consequences of these differences on public health pronouncements, also needs to be highlighted. Third, the difficulties encountered within rural settings when attempting to evaluate physical activity/inactivity with self-report or subjective-measures of physical activity must be acknowledged, and an argument will be made for greater use of objectively-measured PA in rural settings.

1.2. CHRONIC DISEASES OF LIFESTYLE: A GLOBAL, REGIONAL AND NATIONAL EPIDEMIC

The recent technical report of the Medical Research Council of South Africa defines CDL as *“a group of diseases that share similar risk factors as a result of exposure, over many decades, to unhealthy diets, smoking, lack of regular exercise, and possibly stress. The major risk factors are high blood pressure, tobacco addiction,*

high blood cholesterol, diabetes, and obesity. These result in various long-term disease processes, culminating in high mortality rates attributable to strokes, heart attacks, tobacco- and nutrition-induced cancers, chronic bronchitis, emphysema, renal failure, and many others.”⁵⁶⁸ ii The global and regional importance of CDL has also been highlighted in two series published in *The Lancet*.^{520,521}

In their landmark series of papers, reporting the results of the GBD Study,⁴³⁶⁻⁴³⁹ Murray and Lopez state that “the probability of a man or woman dying from a non-communicable disease is higher in sub-Saharan Africa and other developing regions than in established market economies”.⁴³⁸ For 2020 they predicted that for developing regions, ischaemic heart disease and stroke (9.4%) would contribute more to burden of disease than HIV/AIDS (2.8%).⁴³⁶ Using more recent data, it is estimated that for the year 2002, CDL contributed more to global morbidity and mortality than HIV/AIDS (Table 1.1).³⁸⁶

Table 1.1. Current and predicted regional and global burden of disease for HIV/AIDS and selected non-communicable diseases.

	Morbidity (% of total DALY's)								
	Sub-Saharan Africa			Established Market Economies			World		
	2002	2030	% change	2002	2030	% change	2002	2030	% change
HIV/AIDS	17.0	23.2	+68	0.5	0.5	-2	5.5	12.1	+125
CDL	3.5	5.2	+85	18.1	18.6	-2	11.1	13.4	+25

	Mortality (% of total deaths)								
	Sub-Saharan Africa			Established Market Economies			World		
	2002	2030	% change	2002	2030	% change	2002	2030	% change
HIV/AIDS	20.0	25.8	+70	0.3	0.2	+15	5.0	8.9	+9
CDL	10.5	15.2	+91	40.8	40.5	+20	31.0	34.8	+44

constructed from data in Mathers and Loncar³⁸⁶; DALY's = disability-adjusted life yr; CDL = chronic disease of lifestyle (diabetes mellitus and cardiovascular diseases); % change calculated from actual deaths and DALY's reported in Mathers and Loncar³⁸⁶ and not the percentages for 2002 and 2030 in this table

ii The technical report, which provides an excellent 10 year review of CDL and risk factors for South Africa is available online at <http://www.mrc.ac.za/chronic/cdl1995-2005.pdf>.

In comparison with EME, SSA countries displayed higher morbidity and mortality due to HIV/AIDS compared with CDL or non-communicable diseases (Table 1.1). However, in comparison with global and EME, SSA predictions for 2030 suggest far greater changes in CDL morbidity and mortality. In fact, the predicted increases in SSA CDL morbidity and mortality are greater than that for HIV/AIDS (Table 1.1).

Nationally, while HIV/AIDS is the leading cause of death (29.8%), CDL (stroke, ischaemic heart disease, hypertensive heart disease, diabetes mellitus) account for 17.1% of all deaths for 2000.⁸⁹ The top three causes of death in the Western Cape Province are ischaemic heart disease and stroke (20.8%) and HIV/AIDS (8.4%).⁸⁹ Importantly, stroke, an important transitional disease,⁹⁰ is one of the top three causes of death in seven of the nine provinces.⁸⁹ Moreover, South Africa is characterized by a quadruple burden of disease arising from HIV/AIDS, homicide and road accidents, CDL such as ischaemic heart disease, and pre-transitional diseases and conditions related to poverty and under-development.⁸⁹

A landmark series of papers published by the South African Comparative Risk Assessment Group in 2000 estimated the burden of disease attributable to selected CDL and associated risk factors (diabetes, excess body weight, high cholesterol, high blood pressure, PI, smoking).⁴⁵⁴ Seen as major risk factors, these six factors together contributed to 36.7% of mortality and 13.4% of morbidity in South Africa for the year 2000.⁴⁵⁴

In terms of economic burden, the estimated cumulative projected loss in national income for 2006-2015 in low- and middle-income countries, due to heart disease, stroke and diabetes, is USD 83.8 billion.³ For South Africa, the estimated cumulative loss is USD 1.88 billion or 0.7% of gross domestic product for 2007, such that the 2015 loss would escalate to 133% of the 2006 loss.³ Of particular concern is that CDL, specifically cardiovascular disease (CVD) -related disability will dramatically affect the South African workforce (35-64 yr of age) and it has been estimated that disability payment for 2000 (USD 70 million) will increase eight fold in 2040 (USD

600 million).³⁴⁸ For low- and middle income countries, just under 50% of deaths due to CDL will occur in the younger cohorts (<70 yr), which is just under two-fold higher than that expected for EME.³

1.2.1. Obesity

Excess adiposity, in particular abdominal or visceral obesity,^{33,159} is associated with a number of pathologies independently and synergistically (Figure 1.1).^{97,315}

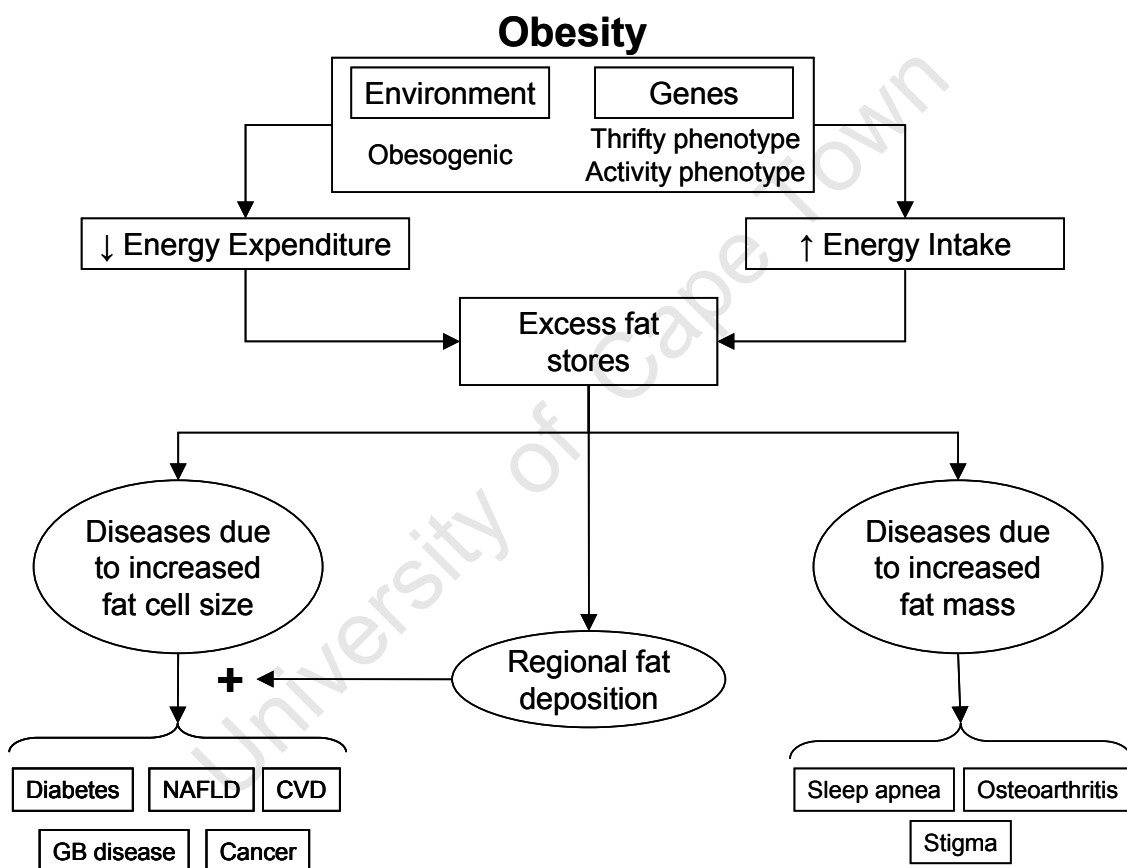


Figure 1.1. Pathology of general and regional obesity. NAFLD = non-alcoholic fatty liver disease, CVD = cardiovascular disease, GB = gall bladder (adapted from Gray⁹⁷).

It is generally accepted that the last quarter of the twentieth century has seen a rapid global increase in overweight and obesity^{273,497} and in 1997 the World Health Organization recognised obesity as a major public health problem of global proportions.²⁹¹ Such a large and rapid increase in global obesity has been attributed

primarily to deleterious changes in the environment ²⁷⁴ and in those individuals with an increased genetic predisposition to obesity, being physically active significantly reduces the risk of obesity.³⁶⁶

A recent estimate suggests that for 2005, 33.0% of the world's adult population is overweight or obese.³⁰⁹ By 2025 the global prevalence of adult overweight or obesity is predicted to reach 57.8%.³⁰⁹ This represents a change of 182% assuming regional secular trends from past data and population growth and demographic shifts.³⁰⁹ For SSA countries, the number of overweight or obese adults in 2005 was 73.4 million which is predicted to escalate to 298.9 million in 2030.³⁰⁹ This translates to massive changes of 272% to 383%, which dwarf the changes in EME countries (15% to 95%). There is also concern at the dramatic rise in childhood obesity in developing countries, giving rise to high prevalences of the paediatric metabolic syndrome.³⁰⁸ Results from the 1998 SADHS found particularly high rates of obesity (body mass index, BMI ≥ 30 kg.m⁻²) amongst black females and white males, matching 1988-1994 prevalences from EME, and far higher than prevalences reported for other SSA countries.⁵⁰⁹ Of concern, the high prevalence (42%) of abdominal obesity (Waist-to-hip ratio >0.85) in South African females.⁵⁰⁹ The prevalence of adolescent and adult obesity has not changed significantly over the five-year period spanning the 1998 and 2003 SADHS.¹⁵⁶ Using the 1998 SADHS dataset, the South African Comparative Risk Assessment Group recently reported population attributable fractions for type 2 diabetes mellitus (87%), hypertension disease (68%), stroke (45%), ischaemic heart disease (38%) and cancers (13-61%).²⁹⁹ Importantly, because obesity is associated with a number of other CDL,⁹⁷ the global and regional obesity epidemic ⁵⁰⁴ is driving the increase in CDL both globally and regionally.^{386,419,438} National paediatric overweight and obesity prevalences are similar to 1976-1980 EME prevalences.²⁵ However, in congruence with the adult results,⁵⁰⁹ white children and black girls are nearing 1988-1994 EME prevalence levels.²⁵

Taken together, these results create a grim picture not only for SSA but more importantly for South Africa. Not addressing the current high levels of CDL and

associated risk factors, already present in large segments of the South African population, will have disastrous implications for not only on the physical health and economy of the country, but more importantly, with the current HIV/AIDS epidemic, on the traditional family structure. The elderly, at higher risk of CDL, will be expected to care for their ailing adult children and orphaned grandchildren.⁵⁶⁷ The emotional and psychological impact on communities, where the elderly are usually cared for by their children, will be substantial.⁵⁶⁷ In fact, it is predicted that depression will be one of the top three contributors to disease burden (4.7% to 9.8% of total DALY) in high, middle and low income countries.³⁸⁶

1.2.2. Epidemiological Transition

To describe the complex and at times seemingly contradictory, changing patterns and prevalence of diseases over time and within populations, has led to the development of three basic approaches or explanatory schemes in demographic transition theory.^{90,91,303}

The Demographic Transition Model describes changes in fertility and mortality in a population. The population moves through four societal stages (pre-industrial, developing, middle income, industrialized), changing from high fertility and high mortality, to low fertility and low mortality. There is thus a shift in mortality profile to more chronic diseases e.g. cancers and CVD, because of an expanded, older population, while mortality due to infectious diseases in the younger population declines.^{90,91,303}

The Epidemiological Transition Model, attempted to address the limitation of the Demographic Transition Model, namely the narrow focus on mortality and fertility to explain changing disease patterns over time.^{90,91,303} Omran developed a model which sought to describe “*complex, long-term changes (over decades or even centuries) in the patterns of health a disease as communities transform their social, economic and demographic structures.*”⁹¹ The original Epidemiological Transition Model posits three sequential eras; era of pestilence and famine, era of receding pandemics, era of degenerative and man-made diseases, which have subsequently

been expanded to include additional stages (delayed degenerative disease, health regression and social upheaval).³⁰³ There are three basic models of the Epidemiological Transition Model which can be applied either to most Western countries (classical or western model), Japan and Eastern European countries (accelerated model), or DME (contemporary or delayed model).³⁰³ Criticisms of the original Epidemiological Transition Model are that it is too simplistic in that certain scenarios do not follow neatly delineated, sequential stages. For instance, middle-income countries comprise different social classes, with the more affluent classes passing through the stages of transition first, followed by the poorer classes. There is thus a protracted bipolar transition with co-existence of transitional, infectious diseases and CDL in the same population.^{90,303} Young *et al.*⁶⁹¹ reviewed the evidence that tuberculosis and diabetes mellitus are causally linked via a bi-directional pathway, likely through impaired immune function and medication side-effects. Moreover, the management regimen of HIV through anti-retroviral treatment increases the risk of various features of the metabolic syndrome.⁶⁹¹ Considering the burden of disease in SSA from diabetes mellitus, tuberculosis and HIV/AIDS, it is indeed sobering to consider the impact that these diseases will have singly and synergistically. Importantly, from an advocacy perspective, reducing the incidence and prevalence of CDL would therefore have a direct effect on combating infectious diseases such as tuberculosis and HIV/AIDS.

The combination of the Demographic- and Epidemiological Transition Models produced the Health Transition Model.⁹¹ Bradshaw and Steyn describe the Health Transition Model as including *“determinants of health status: rising income, the expansion of education, urbanisation, industrialisation and the application of medical technology and improved public health, including better access to healthcare as part of the health services of the country. The health transition refers to the combined changes in fertility, mortality, cause of death composition, disability and the health system’s response to these trends.”*⁹¹ The Health Transition Model thus *“moves beyond demography and epidemiology to include the social and behavioural changes”*.³⁰³

The various models provide useful macro-level paradigms for investigating changing disease patterns in populations. However, interesting nuances are apparent at a finer grain. Tanumihardjo *et al.* explain the paradoxical finding of increasing obesity with increasing poverty on the basis of food security.⁵⁸⁴ Doak and associates have shown that that underweight or stunting and overweight or obesity occur within the same household.¹⁶² Lastly, Ezzati *et al.* found a steep rise in BMI with increasing income. Further rises in income yielded first a plateau in BMI and then a decrease in BMI.²⁰⁰ They suggest that the plateau occurs once a country becomes mainly urbanized such that the rural-urban differences in food and technology are reduced. Importantly, because DME are on a steeper part of the BMI-income curve, overweight and obesity will increase far more dramatically than in high-income countries.²⁰⁰

1.2.3. Nutrition and Physical Activity Transition

The Nutrition Transition Model was pioneered by Popkin,^{491-494,496,498,500} and linked the Nutrition Transition Model to the Demographic- and Epidemiological Transition Models. The Nutrition Transition Model is in essence a Health Transition Model because it focuses on social, economic and behavioural aspects (see Figure 1 and Table 1, Popkin *et al.* ⁴⁹¹). The Nutrition Transition Model has also been discussed from a South African perspective.^{88,642,643} The Nutrition Transition Model posits five broad patterns; collection of food, famine, receding famine, degenerative disease and behavioural change. The last three are typically emphasized because these are the patterns currently experienced by most of the global community. The Nutrition Transition Model is defined as follows: *“The concept of the nutrition transition focuses on large shifts in diet and activity patterns, especially their structure and overall composition. These changes are reflected in nutritional outcomes, such as changes in average stature and body composition. Furthermore, dietary and activity changes are paralleled by major changes in health status and by major demographic and socioeconomic changes”*.⁵⁰⁰

Insightfully, Popkin⁵⁰⁰ and Ng *et al.* ⁴⁴⁷ note the paradoxical and complex nature of the shifts in diet and PA patterns. While the shift to higher fat intake and lower fiber

intake, and decline in PA has resulted in dramatic rises in morbidity and mortality from related diseases, there has been a shift toward a more varied and pleasurable diet and less burdensome, time-consuming activities. The inexorable move to improve the quality of life in a community or population is natural and laudable. The challenge is how to best manage this most natural of human aspirations such that important health aspects are considered when providing communities and populations with the support and infrastructure to realise an improved lifestyle.

Broadly, the Nutrition Transition Model describes a rapid increase in obesity, particularly in DME where the changes have been accelerating rapidly.^{493,494,498} The changes in body composition have been driven by urbanization described by a rapidly increasing proportion living in cities, an urban growth in lower-income countries towards a few large cities (urban conglomerates), a greater proportion of poor within these urban conglomerates, and a migration from rural areas to urban centres.⁴⁹² Concomitantly there is a shift in food intake to edible oils (vegetable oils), calorically sweetened beverages (soft drinks, fruit drinks), away-from-home food (fast food outlets), animal-source foods (egg, poultry, beef, pork) and refined carbohydrates.^{492,500} More importantly, from the perspective of this review, PA changes have been dramatic such that Popkin states *“It may be that the rapid reduction in physical activity rather than diet explains much or more of the increased obesity facing lower and transitional income countries”*.⁴⁹² Similar sentiments have been expressed by other prominent nutritionists.⁵⁰⁵ In this regard, adjusting for a number of confounders, PA level and frequency of consuming restaurant foods are significantly associated ($p=0.001$) with percentage body fat in urban Chinese adults.⁶⁸⁷ Each of these variables explained 9% of the variation in adiposity.⁶⁸⁷ However, large-scale PA initiatives to track changes in the various PA domains were largely absent until the late 1990's⁵⁰⁰ such that researchers have had to rely on population censuses and surveys and other indirect measures^{492,505} not rigorously designed PA self-report instruments. Initiatives such as the China Health and Nutrition Surveyⁱⁱⁱ are providing detailed longitudinal PA and dietary data on these

ⁱⁱⁱ *China Health and Nutrition Survey*: <http://www.cpc.unc.edu/projects/china>

changes and are yielding novel and revealing insights particularly from the point of view of DME.

Despite these shortcomings, the available data shows dramatic changes in occupational PA (OPA) such that high energy activities in sectors such as farming, mining and forestry have shifted to the more sedentary service, manufacturing and commercial sectors.^{120,492,497,500} Moreover, within the same occupations, technological innovations have reduced the EE requirements of those occupations (Figure 1.2).

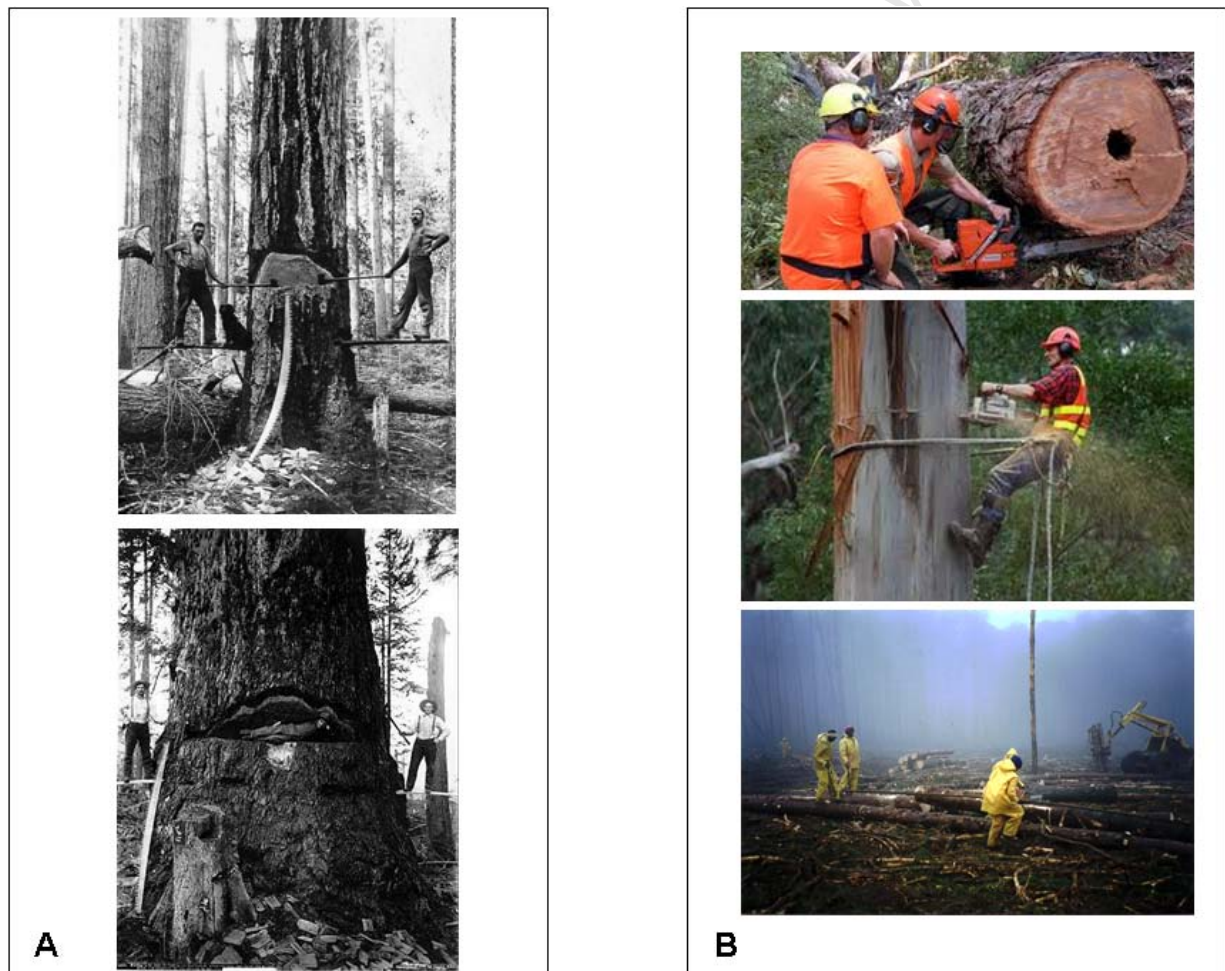


Figure 1.2. Logging: before (A) and after (B) mechanization.

Far more households have access to motor vehicles reducing active transport. Leisure patterns have shifted to more sedentary pursuits with the advent of technology (television, computers). Within the household, day-to-day activities have changed to a more sedentary profile.⁶⁹ Modern technologies, coupled with electrification²⁷¹ and piped water, have transformed home production (food preparation and processing, cleaning). In short, there is a shift away from an energy-intensive, pre-industrial agrarian economy towards a sedentary, mechanized, information-driven industrialised economy.^{492,500} In order to counter the deleterious effects of the “*Stone Age to Chip Age Transition*”⁶⁰¹ some have suggested that we travel “*Back to the Future*” to find the solution!⁴⁵⁸

Within the broader context of the transitional models, there have been few attempts to isolate and study the Physical Activity Transition.^{306,333,423,424} Of particular interest is the recent paper by Katzmarzyk and Mason wherein a Physical Activity Transition model is elucidated (Figure 1.3).³⁰⁶ Of further import are the results from the more than 8000 Chinese adults participating in the China Health and Nutrition Survey which shows first that from 1991-1997 there was significantly increased sedentariness in occupations with increases in income and education in men and women (OR ranged from 2.0 to 8.8).⁴²⁴ Considering the mean increase in urbanization over this six-year period, men and women had a 68% and 51% greater odds, respectively of light occupational activity.⁴²⁴ Second, for the period 1991-2000 overweight doubled in both sexes.⁴²³

EE from occupational and domestic PA declined by 22-24% and 51-57%, respectively. Increasing OPA (low to moderate intensity or low to high intensity) reduced body mass by 0.3-0.4 kg in both sexes. Increasing domestic PA reduced body mass by 0.5 kg in men. Ownership of household labour-saving devices (washing machine, refrigerator, microwave, electric pot, pressure cooker) increased body mass by 0.30 to 1.4 kg men and women.⁴²³ It is this transition from high intensity PA to low intensity PA which is difficult to measure accurately with subjectively-measured PA because most self-report measures are not designed with these transitional changes in mind and consequently do not have the required

sensitivity to detect these changes over time.³⁰⁶ The solution would seem to be the greater use of objectively-measured PA, especially since the technology behind activity monitors is currently more reliable, robust and cheaper.

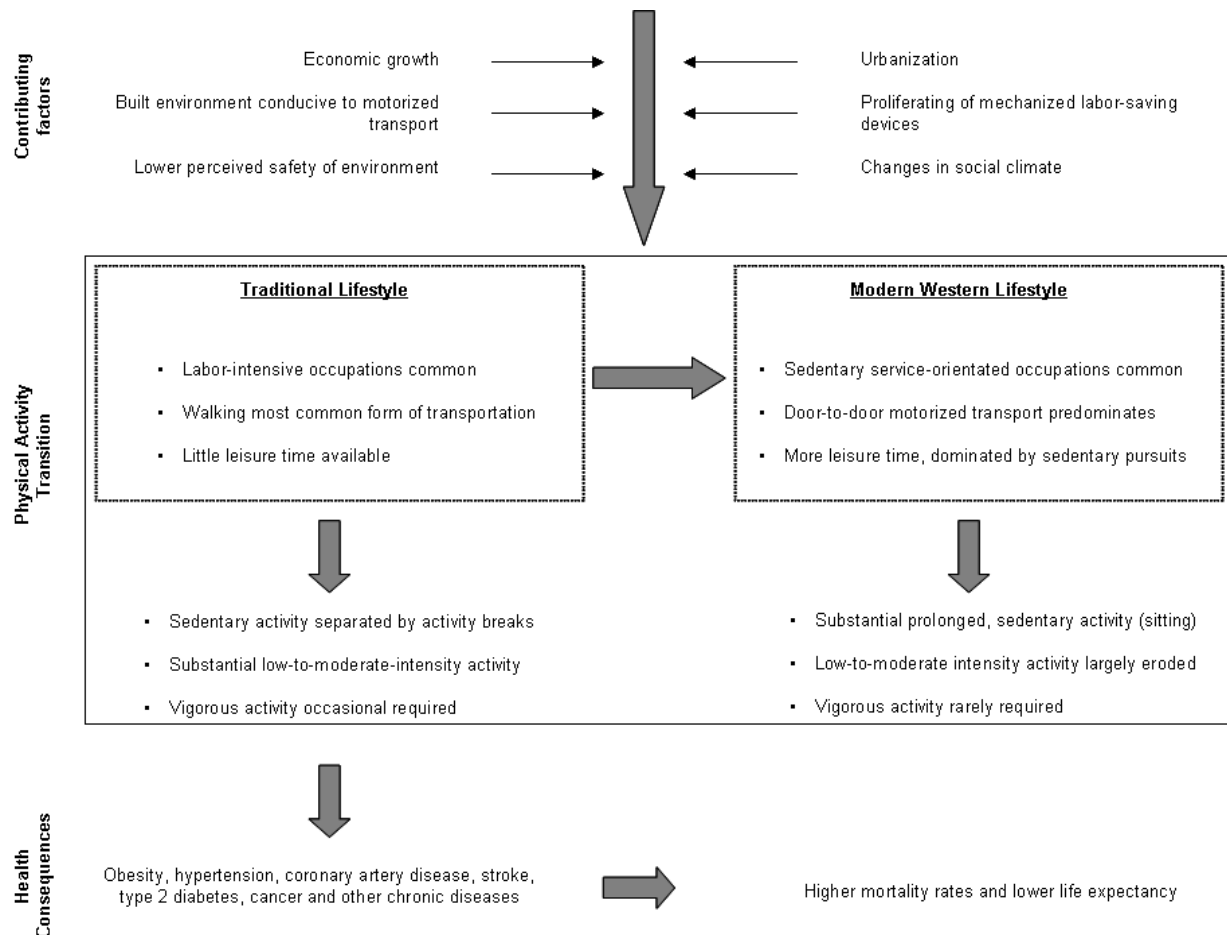


Figure 1.3. Physical Activity Transition. Adapted from Katzmarzyk and Mason³⁰⁶.

Considering the number of large-scale studies in EME that have successfully used movement monitor technology to obtain representative population estimates of PA patterns and trends, greater use of movement monitor technology in settings where Physical Activity Transition is occurring is warranted and feasible.³⁰⁶

Popkin highlights that the changes in diet, PA and obesity are occurring at higher rates in low- and middle-income countries than the changes experienced by EME in the past^{494,495} and highlights key differences pertaining to the speed and timing of

the transition and unique components such as under- and over-nutrition in the same household, influence of biological relationships such as *in utero* and postnatal nutritional stress, and political issues such as the capacity of governments to address the transition.⁴⁹⁵ Interestingly, the adult population attributable fractions for underweight and PI in urban China is 4.3% and 6.3%, respectively and in rural China this trend is reversed to 6.9% and 4.2%, respectively.²⁶² Lambert *et al.* have also highlighted unique aspects of the Physical Activity Transition as it pertains to low- and middle income countries.³³³ First, in more agrarian contexts, seasonal aspects to food production can result in an “energy drain” where food supply is low but PA demands are high. This can result in maternal energy balance being compromised especially during pregnancy leading to retarded fetal growth and low birth weight, predisposing the individual to future CDL. The same increased risk of CDL morbidity applies to children who experience “catch-up” growth. Data from rural Tanzania indicates a high frequency of low weight women during periods of high agriculture-related activity EE. Once the harvesting is completed, the number of low weight women decreases.³¹² Moreover, rural Tanzanian babies delivered during high EE, harvesting months, exhibited lower birth weights compared to those delivered during non-harvesting months, irrespective of the date of conception.³¹¹ More recent work has shown that during the hungry season, a rural Gambian woman loses 2.6 kg (5% of body weight, 25% of body fat) which is equivalent to an energy deficit of 10–15% per day.⁵¹⁴ The fluctuation in maternal body weight mirrored the rates of stunting in infants. Moreover, increased pre-term births mirror increase with agricultural activity and maternal malarial infection.⁵¹⁴ Interestingly, the agrarian seasonality of PA has been described in detail using uni-axial accelerometers on rural Senegalese adolescent girls.⁵⁸ Second, there is evidence that adults display a “thrifty” metabolism such that despite high rates of EE, resting metabolism and diet-induced thermogenesis are lower. Once weight gain occurs, these adaptations reverse.³³³ Third, there are important interactions between PA, health and nutritional status such that illness reduces food production and energy intake, body mass declines increasing the risk of malnutrition, worsening the illness, setting up a vicious cycle.³³³

1.3. PHYSICAL INACTIVITY: A MAJOR CHRONIC DISEASE OF LIFESTYLE RISK FACTOR

As stated in the introduction, it was only in 1992 that PI was formally recognized as an independent coronary artery disease risk factor by an influential organisation from one country.²⁰⁶ In 1997 the GBD included PI as one of six major cardiovascular risk factors.⁵²⁵ More recently, the importance of PI as a risk factor for CDL or “*Diseases of Civilization*”¹⁸³ has motivated the term “*Sedentary Death Syndrome*” or SeDS (Figure 1.4).³⁵¹

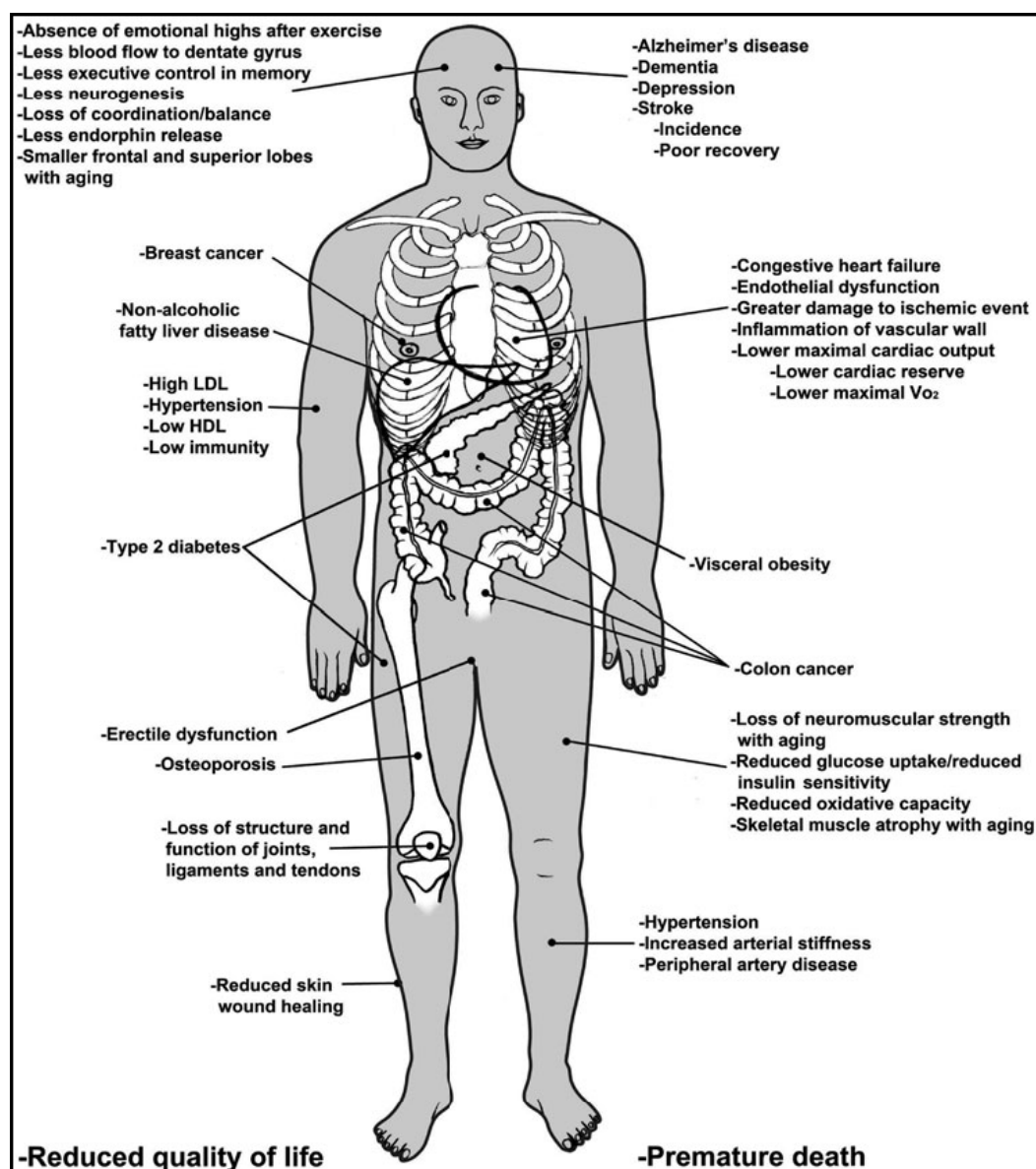


Figure 1.4. Changes induced upon decreasing physical activity from high to low levels. Reproduced from Booth and Laye⁸⁰.

Arguably, some of the earliest evidence for a sedentary lifestyle emanates from Africa in Ancient Egypt where osteoporosis was more prevalent in female high officials but not lower ranking female workers who would have been exposed to greater levels of bone loading through PA.⁶⁹² However, osteoporosis was more prevalent amongst male workers than male high officials because of much greater PA levels (farmers, artisans, labourers, pyramid builders etc) combined with nutritional stress.⁶⁹² Linking this evidence with findings of atherosclerosis in upper class Ancient Egyptians¹⁶ together with their fat intake of more than 50%, with a significant amount coming from saturated fat,¹⁵² it could be argued that a sedentary lifestyle within sections of Ancient Egyptian society, contributed significantly to CDL much like modern urbanized, technology-driven lifestyles do now.

The scientific and epidemiological evidence linking CDL to the rise in PI during the past century and the molecular basis of how PI induces CDL, has been extensively reviewed.⁸¹⁻⁸³ Increased sitting due to watching television or computer use is associated with a 16-49% higher multivariate-adjusted risk for abnormal glucose metabolism¹⁷⁵ and an increased risk for the metabolic syndrome.⁶⁷⁸ For each hr of television watched the risk of all-cause- and CVD mortality is associated with an increased multivariate-adjusted risk of 11-18%, and compared with watching <2 hr.day⁻¹, ≥4 hr.day⁻¹ carries an increased risk of 46-80% for all-cause and CVD mortality.¹⁷⁴ Moreover, there is a strong dose-response association between sitting and all-cause and CVD mortality.³⁰⁴ Similarly, increasing passive transport is associated with a significant ($p=0.01$) multivariate-adjusted increasing CVD mortality risk, such that spending >10 hr.wk⁻¹ riding in a car poses a 50% greater risk of dying than <4 hr.wk⁻¹.⁶⁵⁹ Lastly, for every hour of television watched, 144 fewer daily steps are taken and the risk for not achieving 10 000 steps.day⁻¹ increases by 16%.⁶² Importantly, these increased risks for morbidity and mortality incurred by sedentary behaviour are independent of physical activity.^{174,175,304,659,678} Indeed, limiting the amount of occupational sitting can be as important as sufficient leisure time PA (LTPA) in maintaining daily ambulation levels and BMI.⁶²⁰

From a DME perspective, compared with the lower tertile (PI) of a physical activity index score, African women in the middle and upper tertile, have a multivariate-adjusted 48% and 62% lower risk of BMI defined obesity, respectively ($p=0.001$).³²⁴ Indeed, PI as defined in this cross-sectional study shows the strongest association with adiposity compared with factors such as age, household income, energy intake, educational level and smoking.³²⁴ PI is also associated with a negative CVD profile in African men and women, especially when overweight.³²³ A recent prospective cohort (2004-2008; $n=807$; age ≥ 40 yr) in Central Africa reported a multivariate-adjusted PI hazard ratio of 3.5 to 3.7 ($p\leq 0.027$) for incident type 2 diabetes mellitus.³⁶⁹

Global PI and insufficient physical activity are estimated to be 17.1% (range: 10.3% - 24.8%) and 40.6% (range: 31.7% - 51.5%).¹⁰³ Globally, PI accounted for 3.3% of deaths, 30% of cancer (breast and colon) 21.5% of ischaemic heart disease, 14% of DM and 11% of ischaemic stroke.¹⁰³ Even after adjusting for adiposity level, PI is an independent risk factor for mortality (RR=0.80, 95%CI: 0.78 to 0.82).³⁰⁵ The World Health Survey, which used the IPAQ, suggests that 17.7% (males: 15.2%, females: 19.8%, range: 1.6% to 72.0%) of the world's population are physically inactive.²⁴⁰ Importantly, approximately 45% of South Africans are inactive which would place the country within the five most physically inactive countries of the 51 datasets included in the study and within Africa.²⁴⁰ The SADHS 2003 survey which used the GPAQ reports that 48.0% and 63.2% of South African males and females, respectively are physically inactive.¹⁵⁶ White males and females are the most inactive; 60.2% and 66.8%, respectively. For the Limpopo Province these PI levels are nearly 50% lower than national estimates (males: 24.1%, females: 35.1%). For male and female non-urban Africans the prevalence of inactivity, minimal activity and sufficient activity is 48.0%-63.2%, 22.9%-28% and 14.0%-23.6%, respectively. Not surprisingly, both males and females in the Limpopo Province, reported of the highest transport-related PA. Men with less education reported more work-related PA, but surprisingly this trend was not evident in women.¹⁵⁶ The second South African National Youth Risk Behaviour Study reported that 29.3% and 43.2% of learners participated in moderate and vigorous PA, respectively, while 41.5% participated in insufficient or no PA.⁵¹⁶ Moreover, 34.4% of learners have no physical education classes and

29.3% of learners accumulated >3 hr.day⁻¹ of screen-time (television and computer).⁵¹⁶ More recent data from the World Health Organisation STEPwise Approach to Chronic Disease Risk Factor Surveillance study suggest that the average prevalence for the 22 participating African countries was 83.8% and 75.7% for men and women, respectively according to the World Health Organisation PA guidelines.²⁴¹ When using the GPAQ active cut-points, which includes a frequency requirement, the prevalence drops to 78.8% and 68.4% for men and women, respectively.²⁴¹ Data from Guthold *et al.* suggests caution when comparing survey results using IPAQ and GPAQ instruments as the IPAQ appears to over-report by approximately 20%.²⁴¹

1.3.1. Burden of disease

Globally, of 20 leading risk factors, PI (<2.5 hr.wk⁻¹ moderate-intensity activity) contributes 1.3% to the burden of disease (measured in disability-adjusted life-yr, DALY) for 2000 compared with 4.4% for high blood pressure, 2.3-2.8% for high BMI and cholesterol and 1.8% for low fruit and vegetable intake.¹⁹⁸ The population attributable fractions for stroke and ischaemic heart disease was 7% and 22%, respectively compared with range of 12-21% for tobacco and BMI. Population attributable fractions for ischaemic heart disease in high- and low mortality DME were 21-22%, and 22% for EME.¹⁹⁸ In another report Ezzati and colleagues considered the estimated contributions of major risk factors to global and regional burden of disease.¹⁹⁹ PI was estimated to contribute to less than 0.2-1.1% to DALY and mortality in Africa, compared with 3.4-13.1% globally.¹⁹⁹ Using data from the 2003 World Health Survey, SACRACG reported PI population attributable fractions of 30% for ischaemic heart disease, 27% of colon cancer, 22% of ischaemic stroke, 20% for DM and 17% for breast cancer.³⁰⁰ PI was estimated to have caused 3.3% of all deaths and 1.1% of all DALYs for 2000.³⁰⁰ In rural and urban China the all-cause mortality population attributable fraction for PI is 4.2% and 6.3%, respectively.²⁶²

While there is an impressive, plethora of data describing the relationship between PI and burden of disease, data describing the economic burden of PI, and the cost-effectiveness of physical activity is less abundant. Few studies have considered the

economic costs of inactivity and have focused more on the economic costs of obesity.⁴⁹⁹ Arguably, Popkin *et al.* provided the first comprehensive analyses on the economic costs of diet, physical activity and obesity-related CDL, using China as a case-study.⁴⁹⁹ An important finding of the analysis was that the indirect costs are far higher than direct medical care costs. For 2000 and 2025, the direct effects of low physical activity were estimated to cost USD 1.4 billion and USD 1.5 billion, respectively, approximately 0.1% of China's gross national product (GNP). The indirect costs of low physical activity via overweight/obesity for 2000 and 2025 was estimated at USD 353 million and USD 651 million, respectively; a change of 84.4%. The direct costs of low physical activity on cancers, coronary heart disease, type 2 diabetes mellitus and stroke are predicted to change by 6.3-42.5% from 2000 to 2025. The direct and indirect effects of physical activity and dietary factors are estimated to rise from USD 5.9 billion in 2000 to USD 6.1 billion in 2025, which equate to approximately 0.5% of China's GNP or 2.1% of South Africa's gross domestic product for 2009.

1.3.2. Secular changes in Physical Activity

The dramatic reduction in physical activity seen in EME has been driven first by, automation in industry which on the positive side reduced the onerous, drudgery of many occupations often done in stifling, dangerous conditions⁴⁷⁰ and the change to more sedentary occupations (information technology, service occupations).^{49,210,505} A telling observation is that one of the classic cohort studies in Physical Activity Epidemiology relating OPA to mortality namely the San Francisco longshoremen study *"would not now be possible because the proportion of men in the highest energy category has fallen from 40% to 5%"* (Figure 1.5).⁵⁰¹

North American trends for the period 1950-2000 suggests that because of declines in occupational, transport, household PA domains with increases in sedentary activities and slight increases in LTPA, total PA has declined dramatically.¹⁰⁰ A more recent analysis suggests that declines in daily OPA-derived energy expenditure accounts for a significant fraction of the increase in adiposity of the adult US population.¹²⁰ Of all the US private sector jobs, manufacturing occupations fell from

~30% to ~12% while service occupations rose from ~20% to 43%, for the period 1960 to 2008.¹²⁰ Consequently, there has been a dramatic reduction in moderate intensity occupations from 48% in 1960 to 20% in 2008 and a concomitant rise in sedentary-to-light intensity occupations.¹²⁰

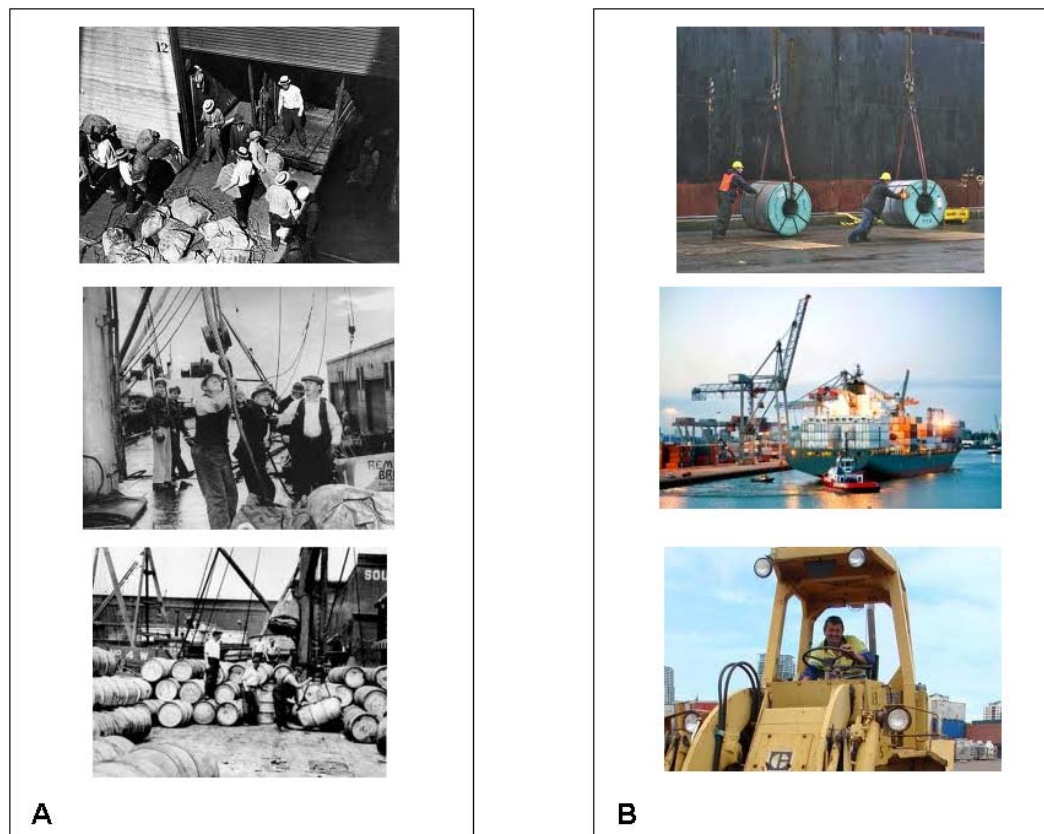


Figure 1.5. Longshoremen: before (A) and after (B) mechanization.

North American men and women are mostly sedentary at work (55-68%) with 26% and 7-20% reporting walking-related occupations and heavy labour, respectively.³²⁵ Similarly, Norwegian heavy OPA declined by more than 50% and sedentary OPA increased by more than 30% over the period 1972-2002, while whether active and inactive in terms of LTPA, BMI increased at approximately the same rates between 1990 and 2002.²³ Paradoxically, although LTPA has increased in some EME, obesity rates have continued to rise⁴⁹ which is likely influenced greatly by the declines in occupational-, household- and active transport PA.⁴⁹

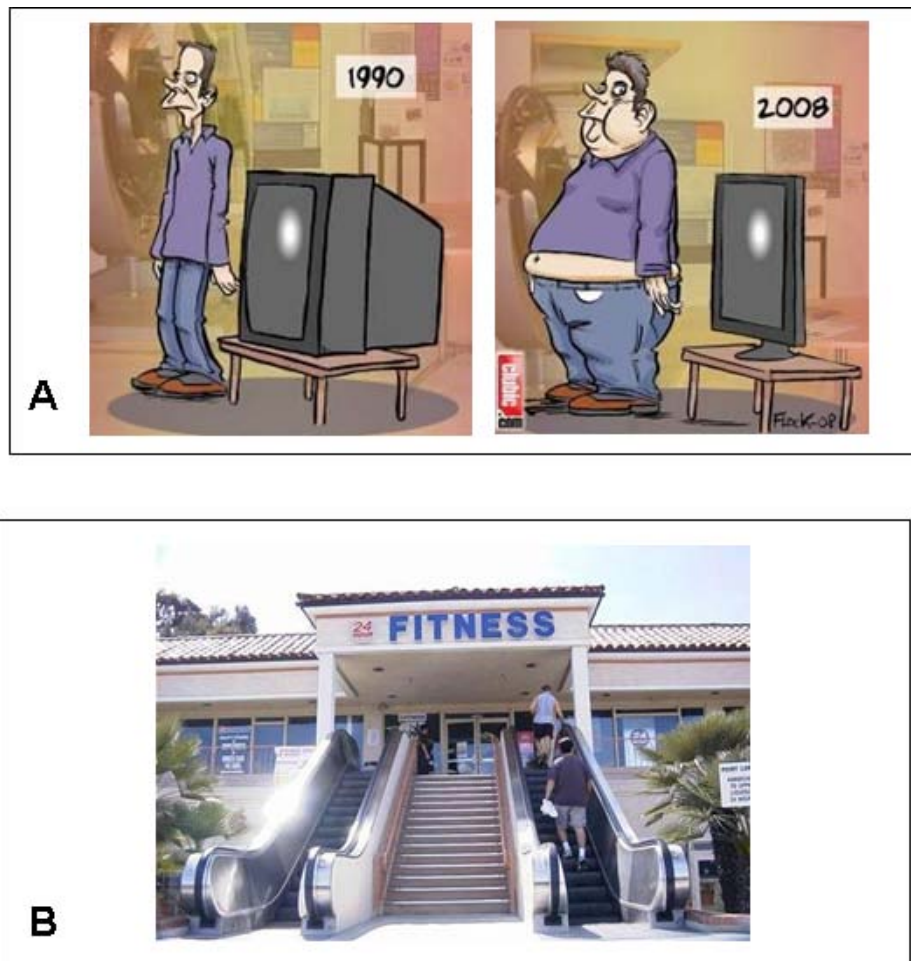


Figure 1.6. Humanity's perennial struggle with energy expenditure

Second, technological developments have reduced EE in the household and yard, during travel and during leisure.^{49,210,505} It is indeed most ironic and sadly humorous that the thinner and smaller technological devices become (Figure 1.6A) and the greater our striving to increase LTPA (Figure 1.6B), the larger and more sedentary humanity becomes!

Third, improved infrastructure such as electrification and piped water has negated manually collecting fuel and water.^{271,378} The greater rise in blood pressure in rural Cameroonians over a ten year period is ascribed in part to reduced PA levels induced by improved infrastructure (highway) linking the rural and urban centres and expanded electrification in the rural site.³⁵³ The authors argue that these two developments increased the likelihood of engaging in sedentary-prone occupations

and acquisition of television sets and motor vehicles.³⁵³ In South Africa 70-74% of women are the usual household fuel (wood) and water collectors.¹¹⁸ Depending on the distance from the household to the source, people spend on average 44-71 min.day⁻¹ and 78-128 min.day⁻¹ collecting fuel and water, respectively. The time spent on housework, including fuel and water collection, ranges from 187 to 224 min.day⁻¹ for women 20-yr and older. The amount of time spent by women on housework is on average 40 min.day⁻¹ higher for households with no appliances (fridge, electric stove, vacuum cleaner, washing machine) compared with households having four appliances.¹¹⁸ In the Ivory Coast rural women provide more than 90% of firewood and water.³⁵⁶

Rising BMI levels (3% in women and 2% in men) over a period of seven yr (1989 – 1996) in ~1000 Mixed-ancestry South African adults has been ascribed in part to electrification, increased use of passive transport and reduced levels of physically demanding work.⁵⁸⁸ The First South African National Household Travel Survey in 2003 contains a fascinating snapshot of South African travel patterns.¹⁵⁷ It is clear that far more walking takes place in rural compared with metropolitan areas, and in the more rural provinces. For instance, 52.5% of rural people walk to work compared with 8.9% for metropolitan workers, while 90.6% of rural students walk to educational centres compared with 56.9% in metropolitan centres. Also, the use of public transport is associated with far higher walking times; 60% and 45% of train commuters have to walk >10 min to the embarkation point and then walk to work after disembarking, respectively. In comparison, only 19.9% and 17.7% of taxi commuters walk >10 min to the embarkation points and from disembarkation to work, respectively. It should be noted that although long walking distances (~10 km) to reach educational centres is associated with higher HDL levels,⁶⁴⁵ this has to be weighed up against aspects such nutritional stress, safety and reduced learning because of fatigue. Consequently, reducing active transport levels for many people is advantageous. There is no doubt that modernizing developments have in many ways improved quality of life, but because there was no concerted, parallel effort to deal with the deleterious effects of these inevitable changes, the negative effects have predominated.

In an attempt to more accurately quantify the dramatic reduction in PA over the last two centuries, comparisons have been made between communities that preserve a traditional lifestyle, eschewing modern technology, to those that have embraced modern living.^{40,43,45,196,377,541,599,600} Another innovative study design is to have people return to a traditional lifestyle for one week to three months.^{185,457,524} A number of these studies have included the use of objectively-measured PA such as pedometers,^{43,45} accelerometers^{185,599} and DLW (doubly-labelled water).¹⁹⁶ These studies have revealed a picture of higher moderate and vigorous PA^{43,541,599} and higher PA levels for total-,^{43,45,185,196,541,599} occupational-,¹⁹⁶ household-³⁷⁷ and active travel domains in traditional settings that likely predominated two to three generations ago.^{43,45,377}

A number of studies have utilized accelerometers⁵⁵⁰ and pedometers^{639,669} to examine the effects of different transport modes on PA. Compared with motorized transport, cycling was associated with a significantly ($p<0.05$) greater daily step count, moderate-to-vigorous PA time, and adherence to HEPA (health enhancing physical activity).⁵⁵⁰ Public transport users accumulate significantly more daily steps ($p<0.04$) and have a 255% greater odds of achieving 10 000 steps.day⁻¹ compared with private motor vehicle users.⁶³⁹ Similarly, train commuters accumulate nearly 30% more steps and have a nearly 300% greater odds of walking 10 000 steps.day⁻¹, compared with car commuters.⁶⁶⁹

1.3.3. Prospective evidence linking changes in Physical Activity and Obesity

Whilst evidence for the dramatic, concurrent secular changes in the decline in PA levels and the increase in weight gain or adiposity is extensive, the evidence linking these trends is less conclusive.⁶⁵³ Prospective cohort studies conducted in EME in children^{328,415} and adults,^{35,189,233,429,486} using objective^{189,233,328,415} and subjective^{35,429,486} measures of physical activity have found that AEE and TEE predict increasing weight gain or adiposity suggesting reverse causality. Within the DME context one study has found no relationship between weight change and objectively-

measured AEE.³⁷⁰ An early study also found no significant relationship between objectively-measured TEE and weight gain in Pima Indians.⁵⁸⁵

In contrast, two recent prospective EME cohort studies, using self-report PA measures, concluded that an increase in AEE was associated with reduced body mass and waist circumference in adults^{184,398} and that exercise pattern over time showed the strongest association with weight changes.¹⁸⁴ The only group that did not significantly increase BMI were the “adopters” who started exercising during the study period, after baseline.¹⁸⁴ There is evidence that increased self-reported PA levels are associated with age- and sex independent decreases in waist circumference, irrespective of changes in body mass, and predicts a lower gain in body weight but only in a younger and leaner cohort (<50 years, BMI <25 kg.m⁻²).¹⁸⁸ Similarly, lean women (BMI <25 kg.m⁻²) who maintained high PA levels (60 min.day⁻¹) gained <2.3 kg body mass over 13 years.³⁴³ However, for BMI ≥25 kg.m⁻², there was no relationship between PA levels and weight gain.³⁴³

AEE predicts changes in fat mass in younger cohorts who as a group gained weight, while in weight stable, older cohorts (>54 years), AEE is positively related to fat mass and fat-free mass.¹⁹⁰ However, the relationship between objectively-measured AEE and weight change in the younger cohorts was small suggesting limited clinical relevance.¹⁹⁰ Likewise, objectively-measured TEE in older adults (70-82 years) is associated with an increase in free-fat mass, but not fat mass.³⁸⁰

Finally, prospective analyses from a DME setting (China Health and Nutrition Survey) suggest that a decrease in NEAT (occupational, household, travel) is significantly associated with an increase in weight gain.^{56,57,423,424}

Taken together, the available data suggests a complex scenario, where placement within the Physical Activity Transition (early, advanced) and level of urbanization, age, psycho-social factors (terminate/initiate exercise behaviour), the current level of adiposity and interactions between the factors probably assume varying importance and will determine the direction of causality (or bi-directionality) between TEE, AEE and weight gain or changes in body composition. Clearly, far more evidence is required, particularly from a DME perspective, to more clearly elucidate an explanatory model.

1.3.4. Patterns of Physical Activity: differences between Developing and Established Market Economies

DME, particularly in the rural areas, but also in some urban areas,³⁰¹ are still characterised by aspects such as active travel (walking, cycling),^{400,555,615} manual yard and household chores^{356,432,598} and manual labour (agriculture).^{356,357,400,432,555,598} Occupational activity, non-recreational leisure activity and walking are PA domains which prevail in Africa^{208,369,400,555} and Asia,²⁸² unlike LTPA which constitutes the bulk of total PA in industrialized settings.³⁸⁴ However, migration to urban centres is characterized by a large reduction in physical activity.⁵⁹⁸ Data from China demonstrate the dramatic PA changes that can occur in a DME over a nine year period where overweight and obesity increased by 8-21% and 108-233%, respectively.⁴²³ EE from occupational and household PA declined by 22-57%, respectively, sedentary occupations have increased by 10% and in the household ownership of washing machines, refrigerators and electric cooking appliances have risen by 14-29%.⁴²³

In EME there is a higher prevalence of moderate-to-vigorous LTPA for those in the upper socio-economic strata versus those in the lower strata, irrespective of the socio-economic indicator used (social class, income, education, asset-based, area of residence)²²⁸ and <20% of those reporting heavy labour occupations have high levels of education.³²⁵ However, in DME at various stages of socio-economic development, such patterns are more complex when including domains such as occupational and active travel PA.⁵³ In DME, greater PA is not always associated with higher educational levels, and a low economic development can be associated with lower PA levels, the latter influenced by factors such as culture and climate.⁵³ Greater occupational- and active transport PA is associated with lower income and educational levels, although this is expected to change as urbanization continues, such that PA accumulated through occupation and active travel will decline inexorably, placing those with lower economic and educational status at greater risk.⁵³

Within rural DME, women often carry a heavy work burden because of the additional household PA (>95% of all tasks) over and above the manual agricultural demands (~33% of all tasks).³⁵⁷ While men work mostly out of home (agriculture, hunting/fishing/gathering) women work within and without the home environment. Moreover women accumulate less time at leisure (females: ~25%, males: ~75%) and non-occupation related travelling than men.³⁵⁶ Improved infrastructure (electricity, piped water) reduces the work burden of rural women in DME (Physical Activity Level: very light=19%, light=62%, moderate-vigorous=18%) but migration to DME urban centres reduces the PA even further (Physical Activity Level: very light=44%, light=42%, moderate-vigorous=14%).⁵⁹⁸ In comparison, the EME gender differences in energy expenditure due to LTPA and household physical activity although following the same pattern, are much smaller (~5%).¹⁶⁴ Findings from SAHDS 2003 reveal some paradoxical trends.¹⁵⁶ Men, but not women, with less education report more OPA. Males in rural provinces (Eastern Cape, Mpumalanga, Limpopo) report the highest LTPA, but not OPA, while females from these rural provinces are the most active at work and leisure. Work and transport PA in urban Africans is 1.3- to 1.8-fold higher than for non-urban Africans. An expected trend was rural provinces (Limpopo and Eastern Cape) reporting the highest transport PA for both genders.¹⁵⁶ These findings suggest further investigation with objectively-measured PA to either corroborate these counter-intuitive findings or contradict these results suggesting the existence of biases, misreporting and/or misclassification introduced by self-report measures.

Cross-sectional^{31,31,237,399,400,412,412,548,555,555,587} and longitudinal^{565,598} studies report significant differences in PA levels between rural and urban DME settings. Bull *et al.* provide a useful schematic for illustrating the relative importance of different PA domains in a DME and EME (Figure 1.7).¹⁰³ However, there is no universally accepted definition of “rural” and “urban” and as such this dichotomy does not adequately describe the change in living and health conditions because of urbanization.⁶³⁸ Interestingly, PA patterns similar to rural women have been reported for urban African women in an informal settlement.⁶¹² It is plausible that the PA levels of these women is comparable to that of rural residents, considering that informal

settlements often lack modern amenities, much like rural settings.⁶¹² Paradoxically, some deep rural African women are reported to be less physically active than women resident on farms or in informal settlements, suggesting other factors such as culture and climate might have an important impact on PA patterns.³²³ Consequently, the use of an urbanicity index provides a means by which the heterogeneity within categories can be described as well as changes in environment over time.⁶³⁸ Future studies will need to more carefully define the level of urbanicity in the populations and communities. This will make static and dynamic comparisons more meaningful within and between communities. The urbanicity index calculated for urban and rural settings in the China Health and Nutrition Survey has shown that over time urbanization increases at a similar rate in both settings⁶³⁸ and that urbanization dimensions are associated with 40.2% to 80.5% of the decline in total and OPA in Chinese men and women.⁴⁴⁷ It is likely that the crude, dichotomous development or urbanization scales used in a recent meta-analysis resulted in the conclusion that the energy expenditure difference between DME and EME are negligible such that energy expenditure does not explain the lower adiposity levels in DME.¹⁷¹

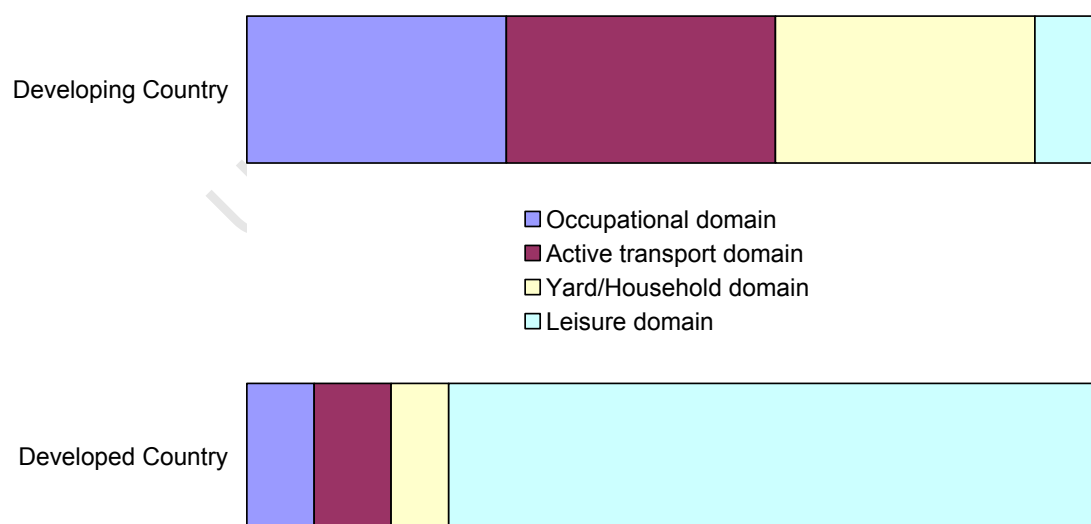


Figure 1.7. Relative importance of physical (in)activity in two hypothetical countries. Reproduced from Bull *et al.*¹⁰³.

However, not only are there relative domain PA volume differences between DME and EME countries, but differences also exist in terms of PA intensity and duration.⁴⁶⁹ Panter-Brick suggests that rural subsistence tasks are usually light-to-moderate in intensity despite appearing physically demanding, spread out over a large portion of the day which is in contrast to industrialized-type productivity which requires high bursts of energy over relatively shorter periods of time.⁴⁶⁹ Mbalilaki *et al.* note that East African Masia and rural Tanzanian residents “*walk (continually relaxed) from morning to evening crossing mountains and hills to their destinations, ..., taking animals for grazing, farming, going to the market or hospital, or fetching water and firewood*” and suggest that such efforts are light-to-moderate not vigorous.⁴⁰⁰ Work effort is characterized by two distinct dimensions, time intensity and energy intensity.⁴⁶⁹ The work pace in rural settings requires long-term endurance and is achieved through a reduced intensity with frequent pauses. The benefits of this time intensive “tortoise” approach are that fatigue is minimized, energy is conserved, heat stress is reduced, and allows contributions to work by individuals with ill-health and pregnant and lactating mothers. In contrast, the energy intensive “hare” approach while maximizing short-term productivity with longer recovery periods after work periods favours physically strong, healthy individuals especially males.⁴⁶⁹

1.4. HEALTH ENHANCING PHYSICAL ACTIVITY IN A RURAL SETTING

The evolution of evidence-based HEPA up until the most recent guideline in 2008⁴⁸⁸ has been described in detail elsewhere.^{21,256,649} The recommendations range from 30-90 min per day, 2.5-5.0 hr.wk⁻¹, 3-6 days of the week, requiring moderate-to-vigorous intensity and address issues relating to energy balance, morbidity and mortality. Generally, these guidelines have been designed with the decline in PA from an EME perspective, and more recent guidelines have begun to cautiously advocate the need to increase “*baseline activity*” defined as “*light intensity activities of daily life, such as standing, walking slowly...*”,⁴⁸⁸ while some state more directly that “*when we consider the emerging evidence on NEAT and inactivity physiology and the relatively small positive energy balance that has produced the obesity epidemic, it is reasonable to conclude that increasing lifestyle PA should be a*

*strategy included in weight management efforts”.*¹⁶⁵ Recent work using objectively-measured PA in Cameroon concludes that the “...*use of total volume of activity may be more applicable to health promotion initiatives in regions with low literacy. It may be more feasible to encourage overall physical activity than to recommend specific sub-dimensions of activity to less educated people*”.³¹ In agreement Bauman *et al.* state that “*In developing countries, and also with reference to global obesity prevention, different kinds of interventions targeting ‘total physical activity’ are needed*”.⁵¹ Similarly, the recent World Health Organization guideline does highlight issues pertinent to DME such as a reduced reliance on LTPA.⁶⁷⁶

It is debatable whether Physical Activity Epidemiology has fully considered a physical activity guideline tailored to the needs of rural DME populations in transition where active transport, household and yard, occupational and total PA are of necessity elevated, yet are likely to decline as the affected population quite legitimately strives to improve aspects such as education, income, and infrastructure. Culturally sensitive and relevant solutions must be sought to replace the declining PA levels in these communities. For instance, traditional games and dance could serve as a core element of health promotion campaigns in rural DME settings.¹⁰⁵ Even within EME there is evidence that in a free-living context individuals in an active occupation (postal workers) while accumulating large volumes of ambulatory activity (17 065 steps.day⁻¹, walking 210 min.day⁻¹) do not comply with bout-based physical activity guidelines.¹¹⁴ Only one active subject complied with ACSM 2007 guidelines, and active subjects accumulated 28 min.day⁻¹ at a moderate walking intensity such that only 15% of active subjects complied with 30 min.day⁻¹ of moderate PA accumulated in bouts ≥1 min.¹¹⁴

Figures 1.8 and 1.9 highlight the fact that PA in rural DME is predominantly light-to-moderate, and does not include moderate-to-vigorous LTPA because of subsistence demands.^{58,205,226,337,444,452,511,597} Recent results from 22 African countries that participated in the World Health Organisation STEPwise Approach to Chronic Disease Risk Factor Surveillance study demonstrated that even when using self-report surveillance instruments OPA and transport PA (including walking) constituted

the bulk of total PA, while the contribution of LTPA was minimal.²⁴¹ Often, the PA patterns can be shaped by cultural demands and practices. For instance, males may practice more leisure activities than females,^{356,432} females carry a greater household PA burden in addition to agricultural activities,³⁵⁶ females are largely excluded from agricultural activities,^{205,432} and younger females carry a higher and more intense workload compared with adult women.^{58,59,224,444} Irrespective of these nuances, what is striking is the absolute and relative levels of NEAT prevalent in these settings. Excluding seated and supine postures, chatting, watching television, and leisure-, social- and religious activities, DME adult rural inhabitants can accumulate approximately 7 to 15 hr, or 28% to 64% of a 24-hr period, in NEAT activities.^{73,74,312,432,452,511,540} Younger DME inhabitants also display elevated levels of NEAT.^{58,59,224,444}

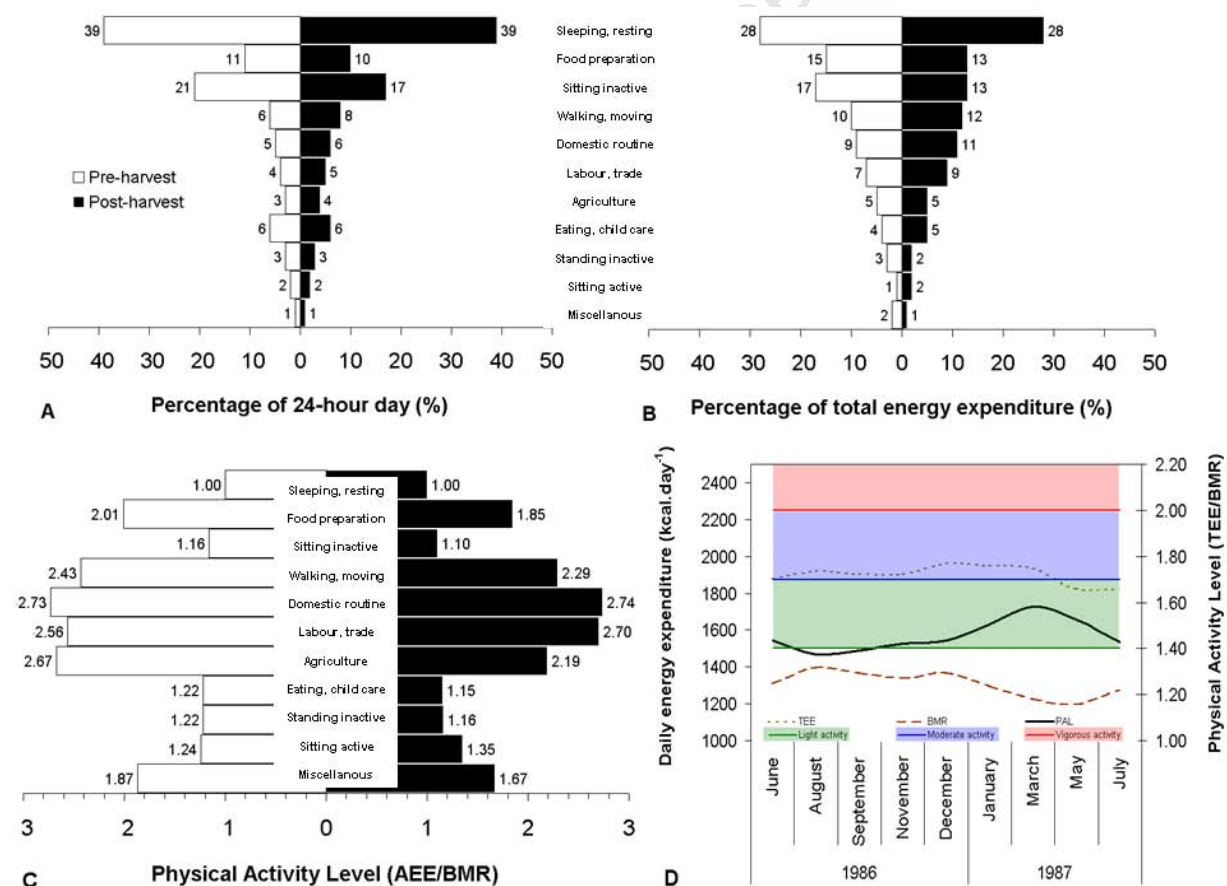


Figure 1.8. Mean activity profiles and monthly trends of total energy expenditure (TEE), basal metabolic rate (BMR) and Physical Activity Level in rural Ethiopian women. Drawn from data in Ferro-Luzzi *et al.*²⁰⁵, Physical Activity Level zones defined according to the FAO/WHO/UNU²⁰¹.

In poor urban settings women lie down and sit less, but stand more than more affluent urban women, and depending on travel requirements poor urban women can either walk more or less than more affluent urban women.^{167,294,337,360,406} Moreover, poor urban women often have to perform more manual, light-to-moderate activities because of a lack modern amenities, although daily television viewing can be as high as three hours or more.^{578,612} Domestic chores, ambulation, food preparation and standing constitute 25-27% (6-7 hr) and 37-48% (500-600 kcal) of total daily time and EE, respectively (Figure 1.8A-B), while the mean activity energy expenditure does not reach three times the basal metabolic rate (Figure 1.8C).²⁰⁵ Although the resulting Physical Activity Level trend remains within the light zone (Figure 1.8D), marked changes in body mass occurred from gains of more than 1.5 kg to losses of more than 3.5 kg. These changes occurred as a result of differences in energy intake which in turn was affected by the interplay between affluence and energy availability. The greater changes in body mass occurred in the more affluent, adipose women, while the poorer women remained lean throughout the year because unlike the more affluent they could not afford to replenish their energy stores during periods of abundance.²⁰⁵

Directly measured EE of 47 different activities commonly found in rural Gambian women, showed no evidence of vigorous PA, assuming $1 \text{ kcal.kg}^{-1}.\text{hr}^{-1} \approx 1\text{MET}$ (Figure 1.9).³³⁷ Rather, 55% of the activities fell in the light range (<3 METs) and 45% fell within the moderate range (3-6 METs). The two activities that were closest to being classified were standing pounding grain ($5.56 \text{ kcal.kg}^{-1}.\text{hr}^{-1}$) and standing, digging with a hoe ($5.15 \text{ kcal.kg}^{-1}.\text{hr}^{-1}$). All household tasks were performed standing or bending. The majority of the food preparation tasks were performed in the sitting position with the exception of pounding grain and winnowing pounded grain which were done standing. During agricultural activities, only 3 of the 19 activities were done in the seated position and even then one activity (sitting digging holes for fencing) was performed at nearly 4 METs. The rest of the agricultural activities were done standing, bending and/or walking. Lawrence *et al.* make the following insightful observation: *“Previous work has suggested that many of the tasks performed by*

African peasant farmers are either moderate or even hard, and indeed this was our subjective impression formed on casual observation. However, the present study, more comprehensive than those previously reported, indicated that the majority of tasks are in fact light."³³⁷ What is also striking is the lack of leisure time activities, the volume of NEAT that is accumulated, even in the seated position and the amount of continual skeletal muscle-loading that is present through standing, bending and walking.

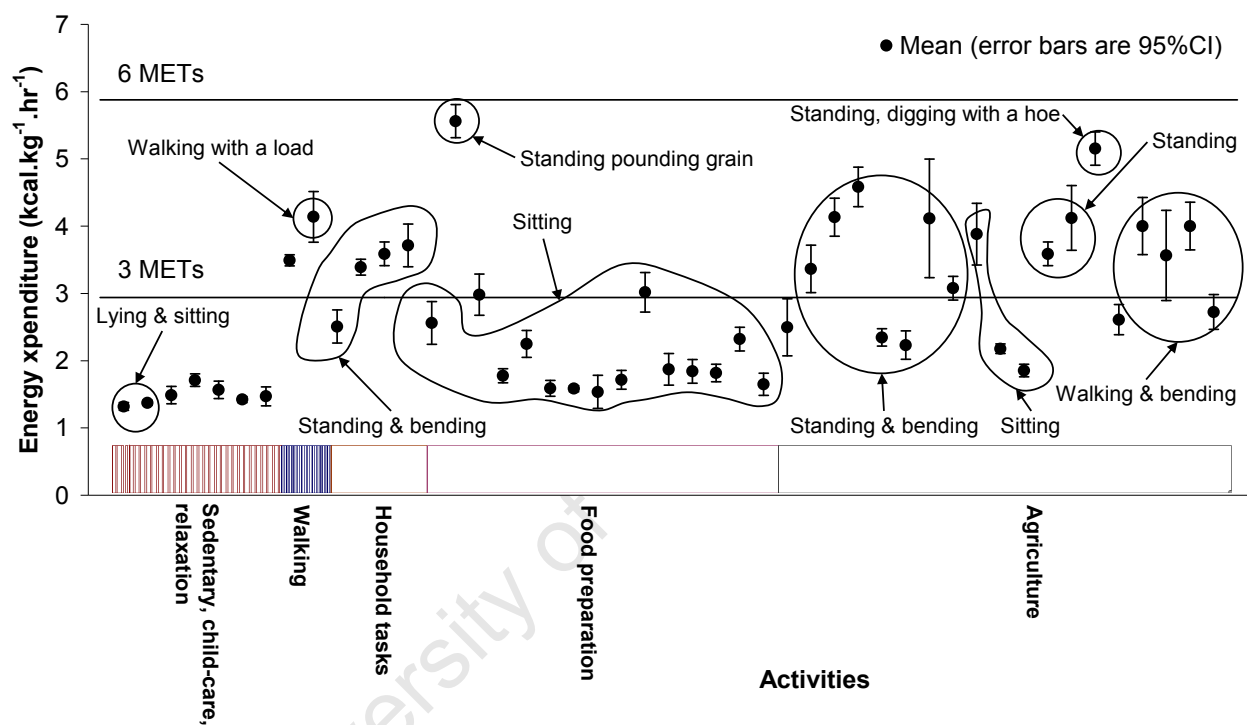


Figure 1.9. The energy cost of common activities in rural African women. Drawn from data in Lawrence *et al.*³³⁷

These examples illustrate the balance that has been established between EE, principally through NEAT, and energy intake such that a relatively stable body mass is achieved in the population. A removal of NEAT in such a community must be replaced with other forms of contextually (safe environment, affordable, motivating) and culturally acceptable physical activity, while allowing the community to develop socio-economically. Considering the importance of NEAT in rural DME in maintaining energy balance and the rapidity with which NEAT is being removed from the energy balance equations, makes it imperative that this particular aspect of EE be carefully documented as these populations advance through the Nutrition and Physical

Activity Transition. NEAT must form part of the physical activity guidelines for these communities, and in order to ascertain the compliance of sufficiently high volumes of light-to-moderate PA will require the use of objectively-measured PA.

1.4.1. Non-exercise activity thermogenesis

The importance of non-leisure, non-exercise, incidental, daily, light-to-moderate activities to total energy expenditure (TEE) was emphasized by Levine in 1999³⁵⁹ who coined the phrase “Non-Exercise Activity Thermogenesis” or NEAT^{355,358,363} which is defined as *“the energy expenditure of all physical activities other than volitional sporting-like exercise. NEAT includes all those activities that render us vibrant, unique and independent beings such as dancing, going to work or school, shovelling snow, playing the guitar, swimming or walking in the modern Mall. NEAT is expended every day and can most easily be classified as NEAT associated with occupation and NEAT associated with leisure”*.³⁵⁵

NEAT has also been defined as *“all non-exercise (non-purposeful) energy expenditures, including incidental movement, lifestyle-embedded activities, chores, maintenance of muscle tone and posture, fidgeting, and shivering”*.⁶⁰¹ The EE of an individual NEAT behaviour is often negligible but seen in the context of many such behaviours over the course of 24 hr, the contribution of NEAT to total daily energy expenditure is often substantial.⁶⁰¹ To illustrate how much NEAT has been removed from our daily lives, Table 1.2⁶⁰¹ is most instructive.

Table 1.2. Examples of factors that have systematically reduced incidental movement for most Canadians.

Category	Example of incidental movement reduction
Domestic	Remote controls (e.g., TV, garage doors, car starters, stereos, fireplaces etc.); voice activated controls; electric can openers; bread makers; self-cleaning ovens; dishwashers; large-capacity laundry machines; electric dryers (replacing hanging clothes out); electric toothbrushes; ride-on lawnmowers; leaf blowers; snow blowers and heated driveways; in-ground water sprinklers; condominium and apartment living (no yard or grounds to maintain); internet (information gathering, shopping, chatting); cell phones
Occupational	Wired workplaces (e.g., fully integrated workspace: phone, fax, internet, etc.); remote work options (e.g., from home); intercoms; telephones and cell phones; teleconferencing; email (avoids a need for writing); voice mail (minimizes the need for recalls); robotic or computerised production and (or) assembly lines
Transportation	Escalators; elevators; motorized pedestrian ways; auto-dependency; GPS (prevents map reading or asking for directions, and gives the shortest route to all destinations); drive-through services (e.g., fast food, convenience stores, ATMs, car washes, etc.); electric-powered windows and cruise-control in automobiles; home delivery; motorized vehicles for children; gasoline-or electric-powered bicycles; motorized scooters; luggage, briefcases, and even shoes with wheels

although the table was constructed for Canadians,⁶⁰¹ it readily applies to any highly industrialized urban setting

Experimental work by Levine and colleagues shows that compared with the supine position, various postures (sitting, standing) with and without any fidgeting can raise EE by 4-94%.³⁶² Manually washing clothes, washing dishes, walking to work (1.3 km) and using the stairs increases EE by 200% (111 kcal.day⁻¹), compared with machine and elevator use.³⁶² Within the working environment of EME, work days are characterised by large amounts of sitting (597 min.day⁻¹),⁴⁰⁶ with free living walking (389 min.day⁻¹) consisting of many (47) short duration (<15 min), low velocity (<1.6 km.hr⁻¹) walking bouts.³⁶⁰ Obesity is associated with longer sitting (150-164 min.day⁻¹), less standing and ambulating (120-152 min.day⁻¹), a lower daily walking distance and nearly 120 min less light activity per day (1.5<METs≤3), compared with lean, sedentary individuals.^{294,360,406} Clearly, EE through OPA can be increased substantially through increases in NEAT behaviours and rather novel technological solutions have been suggested.^{361,401} The NEAT paradigm has been extended further by the concept of a NEAT deficient lifestyle i.e. too much inactivity through sitting resulting in skeletal muscle unloading, loss of contractile stimulation and thus invoking highly specific, deleterious metabolic consequences.^{248,249,251} Additionally, a short sleep duration is associated with suppression of NEAT, weight gain and metabolic disturbances.⁶⁰¹

LTPA accounts for only ~5% of the North American population's EE, and excluding sleeping the largest contributors to EE are passive transport (driving car; 10.9%), occupation (office work, typing; 9.2%) and watching television/movie (home, theatre; 8.6%), while household activities accounted for 20-33% of total EE.¹⁶⁴ Bauman *et al.* argue that to offset the positive energy balance may require more than just increasing LTPA.⁴⁹ They provide simulations suggesting that increasing other domains such as active transport and household PA, while decreasing some of the sedentary leisure time pursuits have significant effects on overall EE and thus energy balance.⁴⁹ The intriguing aspect of this approach is that these activities are often light-to-moderate intensity but when accumulated over a period of 24 hr, contribute substantially to total EE.⁶⁷¹ Pate *et al.* using accelerometry data, illustrate that an individual who does not fulfil HEPA can accumulate 10% more EE than an

individual (*active coach potato*^{249,462} or *weekend warrior*³⁴⁶) who engages in 60 min of moderate-vigorous exercise.⁴⁷² This is the result of spending either 75% or 23% of a 24-hr period in light activity.⁴⁷² An important point to consider is that at these intensity levels self-report measures do not provide the required sensitivity,^{1,453} such that the contributing light activity would not be detected and thus discounted. Consequently, greater reliance on objectively-measured PA will be required to detect light activity and thus increase the estimation of TEE.

A most pertinent study in this regard considered the lifestyle of four groups of young men 20-35 yr of age, from a rural village in Western Samoa (Table 1.3).⁴⁷⁶

Table 1.3. Characteristics of four groups of Western Samoan men differing by occupational and leisure time physical activity.

	Villagers (n=27)	Active (n=32)	Sedentary-active (n=24)	Sedentary-sedentary (n=24)
Overall NEAT level (4=high, 1=low)	4	3	2	1
Traditional lifestyle	Yes	No	No	No
Physically active occupations		Yes	No	No
Active leisure time pursuits		No - minimal	Yes	No
Median Energy expenditure (kcal.day ⁻¹)				
Weekdays	3919 ¹	3841 ¹	3290 ²	2776 ³
Sundays	2747 ^{1,2,4}	2486 ^{1,4}	2570 ^{1,2,4}	2773 ²
Body-mass-index (kg.m ⁻²) ⁶	24.4 (2.3)	25.4 (2.4)	26.2 (2.8)	26.1 (2.4) ⁵
Sum of six skinfolds (mm) ⁶	56.2 (16.9)	65.0 (23.0)	88.9 (32.3)	93.5 (24.2) ⁵
Heart rate recovery (%) ^{7,8}	67.6 (23.0)	65.9 (21.3)	50.4 (30.0)	42.7 (13.8) ⁵
Estimated VO _{2max} (ml.kg ⁻¹ .min ⁻¹) ^{7,8}	48.7 (7.5)	54.9 (9.0)	49.0 (6.2)	43.3 (7.1) ⁵
HDL/T-C ratio (%)	33.5 (8.2)	27.2 (4.9)	25.6 (6.7)	23.8 (6.2) ⁵

constructed with adaptations from data in Pelletier and Baker⁴⁷⁶; values reported as mean (sd); heart rate recovery = percentage of resting heart rate recovered by 1 min post-exercise; HDL = high density lipoprotein, T-C = total cholesterol; ^{1, 2, 3} groups with common number not significantly different; ⁴ significant differences between weekdays and Sundays; ⁵ significant linear trend, $p \leq 0.0081$; ⁶ adjusted for age; ⁷ adjusted for sum of skinfolds; ⁸ $n = 23/29/23/22$

The first group of permanent, full time residents in a rural village engaged in traditional agriculture, fishing and domestic tasks. The second group comprised those employed in physically active occupations (auto mechanics, manual labourers, copra labourers) but participated in minimal leisure time activity. The third and fourth groups were employed in sedentary occupations (bank tellers, clerks, department store workers) who either engaged in leisure time activity (sport) or sedentary pursuits during leisure time. Excluded were those with hypertension, obesity and non-Samoan ancestry. The groups represent the extremes of physical activity

patterns observed in this population. The energy intake and dietary composition of these four groups was remarkably similar; approximately 10 % protein, 60% carbohydrate and 30% fat.⁴⁷⁶

What is evident is that first, as the level of NEAT decreases, EE decreases, specifically weekday EE. Similarly, a host of measures are also significantly linearly related to decreasing NEAT and overall PA levels (Table 1.3). Second, in the face of a sedentary occupation, active leisure time pursuits are associated with adiposity, fitness and biochemical parameters that are not much different from the parameters for sedentary workers following passive leisure pursuits. In other words, active leisure time pursuits cannot compensate for the large loss of NEAT accumulated through a traditional lifestyle incorporating a physically active occupation which fills much of the day with NEAT activities (Table 1.3). This analysis, albeit it cross-sectional, provides a novel snap-shot of the reduction in NEAT within increasing urbanization, as well as the worsening of a host of health-related parameters.

It is intriguing to consider NEAT from the perspective of DME. First, occupational and household PA are declining rapidly⁴⁴⁷ and are linked to changes in body weight⁴²³ and increasing urbanization.^{424,447} Importantly, it is these domains of PA that make up the bulk of daily NEAT.³⁵⁵ Second, much of the NEAT accumulated in DME is not through bouts of vigorous activity but rather prolonged light-to-moderate activity.^{166,469} High levels of time intensive NEAT would thus more accurately describe current PA patterns in rural DME,²⁰⁵ rather than the common misconception of long hours of vigorous agricultural or subsistence work.¹⁶⁶ Consequently, efforts must be made to quantify this particular aspect of PA, especially with objectively-measured PA such as accelerometers, within rural DME populations and to ensure that accelerometry counts are described across the full range of EE rates below moderate intensity.⁴⁷²

The obvious question that arises is; does the available epidemiological and experimental evidence suggest that total PA volume and low-to-moderate intensity

PA is protective? A number of reviews have been published summarizing the available evidence up to 2000.^{158,252,459,484}

1.4.1.1. Epidemiological evidence

The classic studies of Morris and Paffenbarger, detail the protective effect of LTPA.^{464,467} Indeed, there is a large body of evidence supporting the notion that moderate-to-vigorous PA, specifically that which would be classified as leisure (sport, conditioning exercise, recreation) is protective in terms of mortality and morbidity.⁵⁵⁷ Furthermore, the importance of OPA in reducing morbidity and mortality has been detailed in the classic Physical Activity Epidemiology studies^{464,467} and more recent studies have confirmed and strengthened this evidence base. For instance, in EME moderate intensity OPA (jobs including standing and sitting e.g. shop assistant, light industrial worker) are associated with a reduced multivariate-adjusted risk for a fatal or non-fatal coronary heart disease event (30%)²⁸⁴ and type 2 diabetes mellitus (34-47%).²⁸³ In DME, moving from an occupation such as farming to a less energy demanding occupation, was the strongest predictor of weight gain in both sexes⁵⁶ and conversely movement from a low- to high intensity occupation results in a lower body weight.⁴²³ Where OPA has been eroded to that of sedentary status, not participating in LTPA, can increase the risk of disease significantly.⁴³⁰ A recent, large prospective cohort study (n=416 175, 1996-2008) in an Asian country, of which half the cohort self-reported as inactive, found that compared with the inactive group (<3.75 MET-h.wk⁻¹) low-volume LTPA (92 min.wk⁻¹; 15 min.day⁻¹; 3.75 – 7.49 MET-h.wk⁻¹) significantly reduced the risk of all-cause mortality (multivariate-adjusted hazard ratio = 0.86, 95%CI: 0.81 to 0.91).⁶⁶⁸ Life expectancy of the low-volume group was increased by three years, and for every 15 min of daily LTPA accumulated beyond the minimum of 15 min.day⁻¹, the risk of all-cause and all-cancer mortality was significantly reduced by 1-4%. These benefits accrued irrespective of age, sex and disease state.⁶⁶⁸

The pre-occupation with LTPA, and the preponderance of evidence from mostly male cohorts, has over-shadowed the importance of non-exercise PA especially in females who accumulate more PA in household domains.^{423,487,667} Including

domestic and gardening activities in surveillance measures increases the population prevalence of sufficient PA by 12% and reduces the difference between men and women reporting sufficient PA to 2.1%. Prospective studies have provided compelling evidence for the protective effects of light-to-moderate intensity walking against CVD and type 2 diabetes mellitus in women.^{280,345,381} Only relatively recently has evidence been presented detailing the protective effect of household PA in terms of mortality and morbidity, especially in women, and there is even less evidence linking changes in household PA (increasing automation, reduced EE) with increasing adiposity.^{56,423} Increasing non-exercise (household chores) EE, but not leisure EE, is associated with reduced risks (age-adjusted RR=0.49 to 0.71) for all-cause, CVD and fatal myocardial infarction in EME women.⁶⁶⁷ A reduced multivariate-adjusted risk of invasive breast cancer (38%) is associated with a daily routine at home or work which includes heavy lifting or carrying versus sedentarism (mostly sitting) in EME females.²²⁷ Total non-OPA and NEAT (housework + walking + cycling + stair climbing) have a consistent 20-60% reduction in the most active adult DME women with significant trends ($p \leq 0.06$) of reduced adjusted risk across PA categories for all-cause, CVD, cancer and other causes.³⁹⁶ These trends remain for women who report no regular exercise PA but more non-exercise PA.³⁹⁶ In EME men, absence of activities such as gardening, engine repair and growing vegetables is associated with an increased multivariate adjusted risk for all-cause mortality (75-171%) and CVD (88%).²⁴² For both EME sexes, the highest quartile of household PA has a 19% lower adjusted risk for all-cause mortality, while the trends across household PA quartiles was significant for both all-cause and CVD mortality ($p < 0.03$).⁶⁵ In males and females in an EME, a standing, physical or heavy manual occupation is associated with significantly lower multivariate-adjusted risks for all-cause mortality and fatal/non-fatal CVD of 9-27% and 22-31%, respectively.³¹⁰ Increasing levels of daily standing or walking is associated with a reduced multivariate adjusted risk of all-cause mortality in both sexes ($p \leq 0.008$) such that risk reductions are 10-14% for 1-3 hr.day⁻¹ and 20-36% for ≥ 3 hr.day⁻¹, compared with < 1 hr.day⁻¹.²⁸⁷ An assumption is that those engaged in manual labour or heavy-vigorous OPA, are less likely to be physically active outside the work context. However, men and women reporting mostly heavy labour have an approximate two-fold greater

multivariate-adjusted likelihood of participating in regular moderate, vigorous and moderate-to-vigorous activity outside of the work context, respectively.³²⁵

A remarkable prospective study (seven year follow-up) in 2548 middle-aged, normotensive, Japanese white collar professional workers found a strong dose-response effect for total daily life EE and the risk of developing hypertension.⁴⁴²

Table 1.4. Estimated energy expenditure by an activity group for Japanese men.

Activity groups and sample activities	Energy expenditure		
	(kcal.kg ⁻¹ .15min ⁻¹)	(kcal.kg ⁻¹ .hr ⁻¹)	METs *
Sleeping	0.26	1.04	0.9
Rest, talking (sedentary)	0.35	1.40	1.5
Reading, writing, watching television	0.35	1.40	1.5
Talking (standing position)	0.38	1.52	1.8
Taking meals	0.41	1.64	1.5
Dressing, washing face, toilet use	0.44	1.76	2.0
Driving	0.44	1.76	2.0
Clerical work (word processor, office automation tools, bookkeeping)	0.45	1.80	1.5
Riding on vehicles (train, bus: standing position)	0.57	2.28	2.0
Slow walking (<4 km.h ⁻¹) (shopping, taking a walk)	0.69	2.76	2.5
Light manual work (half-sitting or standing position)	0.83	3.32	3.0
Do-it-yourself activities, gardening	0.83	3.32	4.0
Walking at normal pace (4 km.h ⁻¹) (commuting, shopping)	0.86	3.44	4.0
Taking a bath	0.92	3.68	1.5
Cycling (<10 km/h) (commuting, on business, shopping)	0.99	3.96	4.0
Going down stairs	1.10	4.40	3.0
Brisk walking (<4 km.h ⁻¹) (commuting, on business, shopping)	1.23	4.92	4.0
Manual work at moderate pace (eg, loading and unloading goods)	1.43	5.72	6.5
Climbing up/going down stairs	1.52	6.08	5.0
Climbing up stairs	2.03	8.12	8.0
Median (95%CI)		3.0 (1.8 to 4.0)	2.3 (1.5 to 4.0)

Adapted from Nakanishi and Suzuki,⁴⁴² * Compendium values,^{9,10} 1 MET \approx 1 kcal.kg⁻¹.hr⁻¹

A predefined set of 20 daily activities (Table 1.4), excluding exercise because 80% of the participants only exercise on the weekend, formed the basis of a one-day activity record divided into 96 periods of 15 min each. The participants simply had to

indicate which of the 20 categories best described each 15 min period. An activity not provided in the predefined list was carefully described by the participant.

The multivariate-adjusted risk, including adjustment for exercise, across the four quartiles of daily EE was significant ($p < 0.001$) such that the risk of developing hypertension was 16%, 25% and 46% lower across the three highest quartiles compared with the lowest quartile. The multivariate-adjusted dose-response remained even within three categories of normotension (low, normal, high) ($p < 0.001$). The dose-response was stronger for men who hardly exercise as opposed to those that exercise at least once a week; hazard ratios 1.00/0.71/0.64/0.46 versus 1.00/1.03/0.87/0.62, respectively ($p < 0.001$). Considering that the data was collected at entry into the cohort, it is truly remarkable that such significant, large and robust associations were found. Noteworthy is the likely stability and consistency of the actual daily PA patterns, and is probably because these non-shift working, professional white-collar workers often remain with the same employer until retirement. The study also attests to the importance of constructing self-report measures around the PA patterns known to exist within the population in question. Most importantly, the level to which NEAT can be protective is quite remarkable.

As noted by Bell *et al.* there is very little evidence causally linking obesity to longitudinal changes from active (walking, bicycling) to passive (motorized) transport and that in EME there is little variation in the type of transport used because of the high prevalence of trips by private motor vehicles and ownership.⁵⁷ In Great Britain, the increasing prevalence of households with cars from 1950 to 1990, indicative of passive transport, is associated with increasing adiposity, albeit cross-sectional.⁵⁰⁵ Swiss communities free of private motorized vehicle transport, are more likely to be sufficiently active compared with other Swiss communities that are characterized by greater use of passive transport to work and for leisure time activities (43.9% vs. 32.7 to 35.9%).¹⁶³ Only 3.1% of North Americans walk to and from their public transport, spending a median of 19 min.day⁻¹ walking, and of these who walk to and from transit, 29% accumulate 30 min or more of PA per day.⁶⁴ Similar low active commuting rates are reported for North American youth.²³⁶ Furthermore, only 3.8%

of Australians walk to work, <1% cycle to work and more than 64% travel to work by car.⁵⁵ In stark contrast, the South African profile of a typical day's transport consists of 60-63% walking, 13-21% private transport, 13-16% public transport and 0-1% bicycling.¹⁰² Transport PA as an absolute and relative quantity is generally higher in more rural provinces.¹⁵⁶ However, paradoxically urban Africans of both genders report greater absolute and relative amounts of transport PA than non-urban Africans.¹⁵⁶ Whether this is due to biases introduced through the self-report instrument or is simply reflecting the peculiarities of the South African situation where Africans who work in large urban settings but are resident some distance away from their places of employment have to make extensive use of public transport with concomitant increases in active transport (walking), has yet to be probed.

Certainly within EME, there is a strong rationale for promoting walking.³⁴⁴ Considering the effect of active transport PA on health, epidemiological evidence from EME suggests that active commuting (walking, cycling) is associated with an 11% reduction in CVD risk.²⁴⁷ Even after adjusting for a number of confounders, including LTPA, bicycling to work reduces the risk of all-cause mortality by 39%.²⁰ Bell *et al.* found that Chinese men and women from households owning a motor vehicle had an 80% greater odds of being obese than non-motor vehicle owning households.⁵⁷ Moreover, men from households that acquired a motor vehicle between 1989 and 1997, experienced a 1.8 kg weight gain and a 116% greater odds of becoming obese.⁵⁷ For North Americans, every hour spent in a car as a passenger or a driver is associated with a 6% greater odds of being obese, while there is a 4.8% lower odds of being obese for every kilometre walked.²¹² Using public transport (bus), walking or cycling is associated with a 74% lower risk of first myocardial infarction compared with regular commuting via car.⁶⁷⁰ Fitness levels are significantly and positively associated with increasing active commuting for both sexes.²³⁴ Furthermore, compared with passive commuting, male active commuters have a reduced risk of obesity and CVD risk (triglyceride and insulin levels, diastolic blood pressure).²³⁴ Commuters have a 31-46% (females only) and 36% (males and females) reduced multivariate-adjusted risk for a fatal or non-fatal coronary heart disease event²⁸⁴ and type 2 diabetes mellitus,²⁸³ respectively. Over a period of 15

years (1985-2000), female adults at the 75th percentile of baseline weight, equivalent to a BMI=overweight, are predicted to have lower weight gains for 2- and 4 hr.wk⁻¹ (5 kg and 9 kg, respectively), compared with a 13 kg increase in weight for no walking.²³⁵ In urban and rural Cameroonians, EE due to walking is negatively associated with BMI, systolic and diastolic blood pressure, and fasting blood glucose ($p<0.05$).⁵⁵⁵ In fact, it may be that the differences in EE between rural and urban populations in Africa are determined more by the amount of walking than by physically demanding agricultural activities.⁵⁵⁵

There is some conflicting evidence as to whether active commuting, household or yard and OPA is indeed protective. Paradoxically, urban Chinese men who accumulate >30 min.day⁻¹ and >60 min.day⁻¹ through LTPA and commuting plus LTPA are 57 and 66 times, respectively more likely to suffer from hypertension compared with men accumulating no PA.²⁸¹ This was attributed to mental loads imposed by long commutes and greater exposure to salt intake during commuting.²⁸¹ Similarly, compared with men and women achieving up to 7 hr.wk⁻¹ of heavy leisure and OPA, those achieving no heavy activity or accumulating more than 40 hr.wk⁻¹, have a 65-69% higher multivariate-adjusted (including light PA) risk of experiencing myocardial infarction or stroke.⁵¹³ In EME, participation in household PA is associated with a ~30% lower risk for all-cause mortality but not for fatal or non-fatal CVD events after adjustment for covariates including BMI⁵⁶⁰ and heavy domestic work is related to higher BMI and total cholesterol in men ($p\leq 0.002$) and lower systolic blood pressure in women ($p=0.009$).⁵⁶¹ Increasing levels of household PA is not associated with a lower risk of being obese in either gender ($p>0.1$), but there is a significantly lower risk of obesity with increasing levels of brisk walking and sport and exercise ($p<0.001$).⁵⁶¹ Men and women who achieve PA recommendations through domestic PA are more likely to be obese and have poor health compared with those who achieve required PA levels through walking or sport and exercise. It is likely that these findings are the result of reverse causality.⁵⁶¹ Data from a case-control study in urban India reports significantly increased multivariate-adjusted risks for acute myocardial infarction for >8 hr at work (90%), >2 hr standing at work (85%) and <2 hr walking at work (88%).⁵¹² Adjusting for leisure time and sedentary

activities did not alter the relationship between total work time and morbidity. Strenuous activity at work was also associated with an increased morbidity (23%), but not significantly so. Total energy expenditure and other PA categories such as household chores were not related to morbidity.⁵¹² As with other studies,²⁸¹ the increased mental load at work and other lifestyle behaviours not measured, likely accounted for the increased morbidity risk with work-related PA measures.

1.4.1.2. Experimental evidence

In 1994, Despres and Lamarche published their seminal review, “*Low-intensity endurance exercise training, plasma lipoproteins and the risk of coronary heart disease*” and introduced the concept of “metabolic fitness” whereby low-intensity training (daily, ~1 hr duration, ~50% maximal oxygen uptake; VO_{2max}) would reduce important metabolic variables considered coronary heart disease risk factors, independent of changes in fitness (VO_{2max}).¹⁵⁸ Since 1994, data has accumulated corroborating and extending the concept of “metabolic fitness” through participation in daily, prolonged, low-intensity physical activity. Insightfully, Despres and Lamarche suggested that, unlike prolonged low-intensity exercise, the ACSM prescription of three days.wk⁻¹, 20 min per session, 50-85% VO_{2max} ,¹⁵⁸ would have limited impact on total energy expenditure and thus adiposity levels, predating the Institute of Medicine guidelines⁹⁹ by nearly a decade.

Work published by Pescatello and colleagues during the late 1990’s suggest that PA, including daily living activities, performed 3-7 times per wk, 10-60 min per session to accumulate 20 to ≥60 min per day of PA, from as low as 20% VO_{2max} would be appropriate for older populations. Importantly, the PA is accumulated through movement resulting from daily living activities, such as active transport and household and yard activities, performed throughout the day.^{98,480-484} Of relevance was the significantly reduced blood glucose concentration, waist circumference, systolic blood pressure and improved blood lipid and lipoprotein profile with increasing daily movement category in elderly samples. The movement categories (<3 hr.day⁻¹, 3 to <5 hr.day⁻¹, ≥5 hr.day⁻¹), were constructed from the Yale Physical Activity Survey Questionnaire in response to the question, “about how many hours

per day do you spend moving around on your feet while doing things?” Activity examples (2–4 METs) of moving about cited by the study participants included light housekeeping, cooking, doing dishes, grocery shopping, and leisurely walking at the mall.⁴⁸² Earlier work by Reaven *et al.* shows that elderly women (50–89 yr) who report light activity (calisthenics, bowling, dancing, gardening, golfing, horse riding, walking) have an age-adjusted lower resting heart rate (HR), BMI and resting blood pressure than sedentary women, with the trends (sedentary-heavy PA) significant ($p < 0.05$).⁵¹⁵ More recent data suggests arterial stiffness, which is associated with increased CVD morbidity and mortality, is significantly associated with increased daily light PA (sex-adjusted $r = -0.30$, $p < 0.05$) in older adults (> 60 yr).²²² The inverse relationship between light PA and arterial stiffness are even stronger for unfit individuals and persist even after adjusting for moderate-to-vigorous PA.²²² Similarly, Yates *et al.* have reported lower levels of CRP, IL-6 and TNF α with increased walking activity independent of a number of confounders and other forms of physical activity in elderly males and females screened for type 2 diabetes mellitus.⁶⁸⁸ However, there is evidence that the walking activity in type 2 diabetics is accumulated at low walking speeds,²⁹⁷ sufficient to induce positive changes on inflammatory markers.⁶⁸⁸

Lifestyle PA interventions, which emphasise an unstructured approach to increasing PA, in sedentary males and females¹⁷³ and obese women²² with an age range of 20 – 60 yr, have shown significant reductions in submaximal HR, percentage body fat, systolic and diastolic blood pressure, and blood lipids and lipoproteins and increases in VO_{2max} . The changes in PA were tracked using a tri-axial accelerometer and revealed an increase of 28% in the daily activity counts of the lifestyle-group participants.²² These findings also suggest that “metabolic fitness” can be accrued at relatively low intensities in a younger population.

Results from small, short-term experimental studies conducted with healthy younger subjects, overweight/obese subjects and subjects with diabetes, dyslipidemia, hypercholesterolemia or the metabolic syndrome have found that prolonged, low-to-

moderate intensity exercise (40-60% $\text{VO}_{2\text{max}}$) or self-selected “brisk” walking pace has similar benefits compared with older populations:

- increased the relative fat oxidation during exercise in upper body obese females and obese males by 19-40%,^{635,637}
- reduced weight regain in healthy, weight-reduced obese males if the frequency of exercise is ≥ 3 times per wk,⁶³⁶
- increased absolute fat oxidation during exercise, increased capacity to oxidize intra-muscular triglyceride- and/or VLDL derived fatty acids at rest and increased expression of enzymes coding for key enzymes in fat oxidation in healthy, lean males,⁵³⁹
- increased insulin sensitivity (88% change) in healthy, overweight/obese males and females,²⁷⁸
- retained an increased insulin sensitivity 15 days after cessation of training in healthy, overweight/obese males and females,³⁴
- reduced subcutaneous abdominal adipocyte size in healthy, obese women,⁶⁹⁰
- increased $\text{VO}_{2\text{max}}$ and treadmill time to exhaustion in overweight/mildly obese males and females with mild-to-moderate dyslipidemia and healthy, overweight/obese females with moderately elevated systolic blood pressure,^{28,181}
- reduced triglyceride, VLDL triglyceride and large VLDL particle concentrations, and the size of large VLDL particles in overweight/mildly obese males and females with mild-to-moderate dyslipidemia,³¹⁶
- improved body composition (reduces body mass, fat mass, waist and hip circumference), improved ability to oxidize fats, increases lipid oxidation and decreased insulin resistance in overweight/obese males and females diagnosed with the metabolic syndrome,¹⁷²
- independent of weight loss, obese and non-obese type 2 diabetes mellitus males reduced total and visceral fat and skeletal muscle lipid content,³⁴⁷
- reduced systolic and diastolic blood pressure, body-mass-index and total cholesterol concentration in males and females with type 2 diabetes mellitus,²²⁰

-
- acutely reduced triglyceride and increases HDL-C concentrations for up to 48 hr after a single exercise session, chronically in hypercholesterolemic males,¹⁴³
 - chronically, but modestly, decreased T-C, HDL₃-C and apo A-1 and B concentrations, and increases HDL₂-C concentration in hypercholesterolemic males,¹⁴³
 - increased VO_{2max} and reduced waist circumference, sagittal diameter and LDL-C concentrations in premenopausal, overweight women,⁷⁹
 - increased expression of proteins implicated in lipid metabolism and mitochondrial function, in male and female type 2 diabetes mellitus who decreased plasma insulin levels, insulin resistance and systolic and diastolic blood pressure,²¹⁹
 - reduced postprandial TG in premenopausal women²³⁰ and reduced postprandial concentrations of chylomicrons, large VLDL₁, small VLDL₂, remnant-like lipoprotein cholesterol, TG, lower apo ratios in VLDL, lower cholesterol ester:TG ratios in VLDL₁ and VLDL₂ and higher ratios in HDL in middle aged men,²³¹
 - reduced postprandial insulin concentrations in centrally obese men, reduced postprandial TG in lean and centrally obese middle-aged men, and increased postprandial endothelium dependent, small vessel vasodilator function in both lean and centrally obese men.²²⁹

There is also evidence that accumulating PA in bouts shorter than 10 min can have significant health-enhancing benefits although a recent review suggests that more definitive evidence is still required to more confidently promote the health benefits of PA accumulated in bouts <10 min.⁴³³ Coleman *et al.* conducted a randomized experimental trial with sedentary adults to investigate the effects of meeting the ACSM guidelines of 30 min of moderate intensity PA on most days of the week.¹²⁵ Subjects were assigned to one of three walking groups over a period of 16 weeks and were assessed again at 32 weeks after the programme had ended. The participants accumulated 30 min of moderate PA in one 30 min bout, 3x 10 min bouts or through any bout duration 5 min or longer. The amount of PA was similar

across groups at baseline and the increase at 16 weeks and 32 weeks as determined by tri-axial accelerometry and self report. The intensity at which the participants walked was $\pm 70\%$ age-predicted maximum HR. Submaximal fitness increased and systolic blood pressure decreased significantly after 16 weeks in all three groups similarly. At follow-up at 32 weeks, 16 weeks after the programme had ceased, submaximal fitness increased, systolic and diastolic blood pressure decreased and percentage body fat decreased significantly similarly in all three groups.¹²⁵

A randomized seven week stair-climbing experimental study found that previously sedentary young women significantly increased their HDL, decreased T-C and T-C:HDL-C ratio, and reduced their submaximal blood lactate concentrations, HR and oxygen consumption.⁸⁵ The novel aspect of this study, conducted in a public access staircase, was that the experimental group progressed from one ascent per day to six ascents per day over seven weeks, with each ascent taking ± 135 s (199 steps, ± 88 steps.min⁻¹), for a total of only 13.5 min per day during the final weeks of the trial. HR after 2 min of stair climbing was $\pm 90\%$ of predicted maximum HR indicating a vigorous classification.⁸⁵

In a randomized, repeated-measures study, healthy young men showed a significant reduction in postprandial plasma triacylglycerol concentrations and resting systolic blood pressure after accumulating 30 min of brisk treadmill walking in 10 bouts of three min each throughout the day.⁴²¹ The intensity of each walking bout was set at a self selected pace (41.4 ± 1.8 %VO_{2max}), with each bout was separated by 30 min. The bouts were as effective as a continuous 30 min walking bout. The results of this study were similar to an earlier study by the same group which employed more vigorous treadmill running at 70 %VO_{2max}.⁴²⁰ Moreover, the results of the 10x 3 min protocol produced similar effects to a trial using sedentary men and women aged 34 to 66 yr, where subjects accumulated 30 min of PA through 3x 10 min treadmill walking bouts at 59.6 ± 1.2 %VO_{2max}.⁴³⁵

The findings of these three studies were remarkable considering the very short bout durations. These results also highlight the distinct possibility of underestimating lifestyle PA with current self-report measures. Because of the difficulty in identifying bouts of PA <10 min, especially in free-living conditions, greater use must be made of objectively-measured PA to investigate the efficacy of short bouts of activity.⁴³³

Prior to the feasibility of measuring free-living PA with affordable, reliable and accurate objectively-measured PA, intervention and experimental studies utilized self-report measures. The accurate and reliable estimation of accumulation of light-to-moderate PA is problematic with self-report measures, which tends to estimate vigorous PA more accurately.^{6,290,313,586} Considering that the new generation HEPA guidelines focus specifically on moderate intensity PA^{257,288,473} it is essential that the use of technology to measure PA be utilized. Consequently, since the seminal paper of Yamanouchi *et al.* in 1995⁶⁸⁶ a number of studies have been reported that have used objectively-measured PA to quantify physical activity accurately where self-report measures would not have provided the required accuracy.

Yamanouchi *et al.* reported that walking more than 10 000 steps.day⁻¹ over a period of 6-8 weeks, significantly reduced body weight and improved insulin sensitivity in obese, type 2 diabetic patients.⁶⁸⁶ The experimental diet and exercise group accumulated on average 19 200 steps.day⁻¹ which yielded a nearly 8 kg reduction in body mass and increased glucose infusion rate and the metabolic clearance rate of glucose by 1.8- and 1.5-fold, respectively. The changes in insulin sensitivity were not seen in the diet only group who maintained their PA levels at 4500 steps.day⁻¹. Importantly, the investigators found that the ambulation was significantly and independently associated with changes in glucose metabolic clearance rate. The achievement of nearly 20 000 steps.day⁻¹ was remarkable and likely the result of the participants being hospitalised during the course of the trial. What the study did show was that the use of pedometers made possible the accurate quantification of a ubiquitous PA, namely walking, which is usually challenging to measure.^{42,298,318,413} In so doing Yamanouchi *et al.* were amongst the first to provide evidence for the health-enhancing effects of large volumes of low-to-moderate PA using objectively-

measured PA.⁶⁸⁶ A more recent study, using objectively-measured PA, has been the first to show that markers of mitochondrial capacity are positively associated with total daily PA independent of sex, age and BMI.¹⁵⁵ Free-living, non-exercising, healthy young subjects wore a tri-axial accelerometer for two 14-day periods and also had mitochondrial enzyme activities determined from homogenized vastus lateralis muscle biopsy samples. What was remarkable was that the daily activity level was within the range of normal daily activities (Physical Activity Level 1.80 to 1.88) although the relationship between the enzyme activities and daily activity levels appear to require 8-72 min.day⁻¹ of moderate-to-vigorous activity.¹⁵⁵ However this intensity requirement is not onerous when considering that the participants spent less than 5% of daily activity in the moderate-vigorous intensity and more than 95% in the light intensity range, and that the accumulated PA time was collected in intervals of 1 min not bouts of 10 min.¹⁵⁵

Since 2000 a number of experimental and intervention studies have been published using objectively-measured PA to quantify high volume, low intensity PA and the effects on blood pressure,^{314,427,434,463,471,633} sympathetic modulation,⁴⁷¹ sympathetic nerve activity,²⁸⁹ arterial stiffness,²²² glucose and insulin metabolism,^{221,422,580} fat distribution and weight loss,^{314,410,422,633} lipid levels and lipid oxidation/metabolism^{106,221,314,602} and mitochondrial capacity.¹⁵⁵ Observational studies using pedometers have shown consistent associations between reduced ambulatory activity and increased adiposity,^{277,551,575,579,582,617,628} increased fasting blood glucose and HbA_{1c} levels⁵⁸² and an adverse cardio-metabolic risk profile.^{535,551,575} Recent ground-breaking experimental^{248,251} and epidemiological²⁶³ work has suggested that low intensity physical activity may have important health benefits in preventing and combating CDL and associated risk factors.

Recent innovative intervention studies have found dramatic deleterious changes in metabolic and body composition and physical fitness measures after a reduction in usual ambulatory levels.^{321,460} Eight to ten young, healthy men walking more than 3500 steps.day⁻¹ but exercising regularly less than 2 hr.wk⁻¹ maintained their habitual dietary intakes but reduced their usual ambulatory activity from more than 10 000

steps.day⁻¹ to less than 2000 steps.day⁻¹ for 2 to 3 weeks. In one sub-study the subjects purposefully used elevators instead of stairs, and passive (cars) instead of active transport (walk, cycle).⁴⁶⁰ After 2 weeks VO_{2max} decreased by 7%, glucose infusion rate decreased by 17% due to a reduced peripheral insulin sensitivity, area under the curve for oral glucose and fat tolerance tests (insulin, C-peptide, triglyceride) changed by +21.0% to +57.2%, and intra-abdominal fat, fat-free mass and BMI changed by +6.8%, -2.2% and -1.4%, respectively ($p \leq 0.05$).^{321,460} After 3 weeks of reduced activity, area under the curve for insulin changed by +78.6% ($p < 0.02$).⁴⁶⁰ These studies highlighted the dramatic and accelerated onset of a host of cardiometabolic risk factors due the removal of NEAT from everyday life. In effect, these results have provided an accelerated time-lapse glimpse into the Physical Activity Transition as it swept inexorably across the industrialized world in two to three generations. These changes, small and imperceptible by themselves but summed together from every domain of daily life, have invoked one of the most fundamental laws of the universe; energy can neither be created nor destroyed, only transformed from one form to another. The resulting energy imbalance has crept across the globe in a deluge of obesity and associated CDL.

The critical role of objectively-measured PA in investigating these domains of PA (sedentary and light), which are difficult to accurately quantify with self-report measures, should be extended into DME settings such that transitions in sedentary and PA behaviours, across the intensity scale, can be tracked with greater precision providing studies which describe these changes in relation to morbidity and mortality with greater statistical power.

1.5. MEASUREMENT OF PHYSICAL ACTIVITY IN A RURAL SETTING

1.5.1. Physical Activity: definitions, theoretical constructs and methods

Physical activity is defined as *“any bodily movement produced by skeletal muscles that results in a substantial increase in energy expenditure above resting energy expenditure”* and has been casually linked to a number of CDL and associated risk factors.¹⁶¹ Lamonte and Ainsworth caution against equating PA with EE and define

these terms or dimensions as follows: *“It is important to recognise that physical activity and energy expenditure are not synonymous terms (see here ¹⁸⁷ for a pertinent example). Physical activity is a behaviour that results in energy expenditure and is typically quantified in terms of its frequency and duration. Energy expenditure reflects the energy cost or intensity associated with a given physical activity. It is a direct function of all metabolic processes involved with the exchange of energy required to support the skeletal muscle contraction associated with a given physical activity”.*³³⁵ These two dimensions, which can be measured directly or indirectly, combine to form a construct; movement (Figure 1.10).

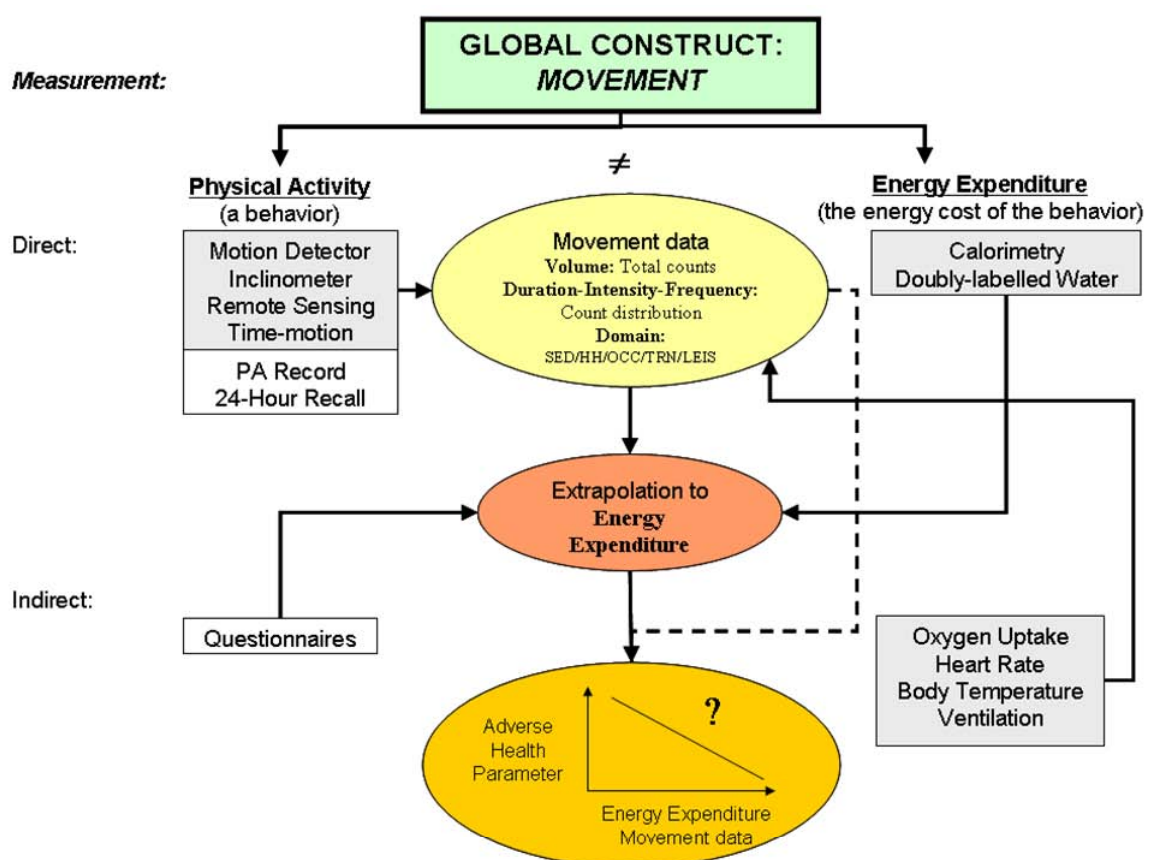


Figure 1.10. A conceptual model of the relationships between movement, physical activity and energy expenditure, as well as methods of assessment. Objective monitoring methods are shaded grey. (adapted from Lamonte and Ainsworth ³³⁵).

Irrespective of the dimension measured, extrapolation to EE is the preferred route because EE is often used when examining the relationship between movement and health outcomes. However, some argue that converting raw accelerometry (movement counts) and pedometry (steps) data to EE is problematic,^{144,349}

suggesting that the movement data be used instead. Indeed, a number of studies relate volume (counts ⁶¹⁴, steps ⁵³⁵) and intensity classification such sedentary,²⁶⁷ light ²⁶³ and moderate-to-vigorous ⁵⁷⁷ to health outcomes. Moreover, there is evidence that it is not only the physical activity-related EE that confers a health benefit but skeletal muscle contraction per se. For instance, resistance training is independently associated with increased insulin sensitivity ¹¹⁷ and improvements in sub-components of the metabolic syndrome ²⁸⁶ after adjusting for a number of factors including other forms of PA. There is experimental evidence that strength training, independent of changes in muscle mass, increases the protein content of key proteins involved in the insulin signalling cascade.²⁷⁵

Of the three components of daily TEE; resting metabolic rate, thermic effect of feeding and activity energy expenditure (AEE) (Figure 1.11), the latter is the most variable ranging from 15% in very sedentary individuals to 50% or more in highly active individuals.³⁵⁸ AEE can be compartmentalized into Exercise Activity Thermogenesis and Non-Exercise Activity Thermogenesis,³⁵⁸ or Voluntary and Spontaneous Activity Thermogenesis.⁵⁵³ The latter, forming part of NEAT, and under greater non-voluntary control.^{358,553} NEAT can contribute 90%-99% of AEE in urban normal weight to obese, men and women who accumulate 5221 to 9575 steps.day⁻¹.^{1,195} In rural men and women who walk 53 to 179 min.day⁻¹, NEAT contributes 100% of AEE.^{73,74,205,226,312,337,511,540} Although the proportional amount of NEAT is equivalent the absolute amount of NEAT can vary considerably. For instance, NEAT in urban, mostly sedentary, normal weight to obese females averages 649 kcal.day⁻¹,^{502,503} while that of non-pregnant non-lactating, pregnant and lactating rural, agrarian women averages 1180, 1427 and 1300 kcal.day⁻¹, respectively,⁵⁴⁷ which translates to an approximate two-fold urban-rural difference. The recent development of multi-sensor movement monitors which integrate signals from accelerometers and several other physiological sensors, are providing more accurate estimates of free-living TEE, especially at the lower activity intensities.²⁹⁵

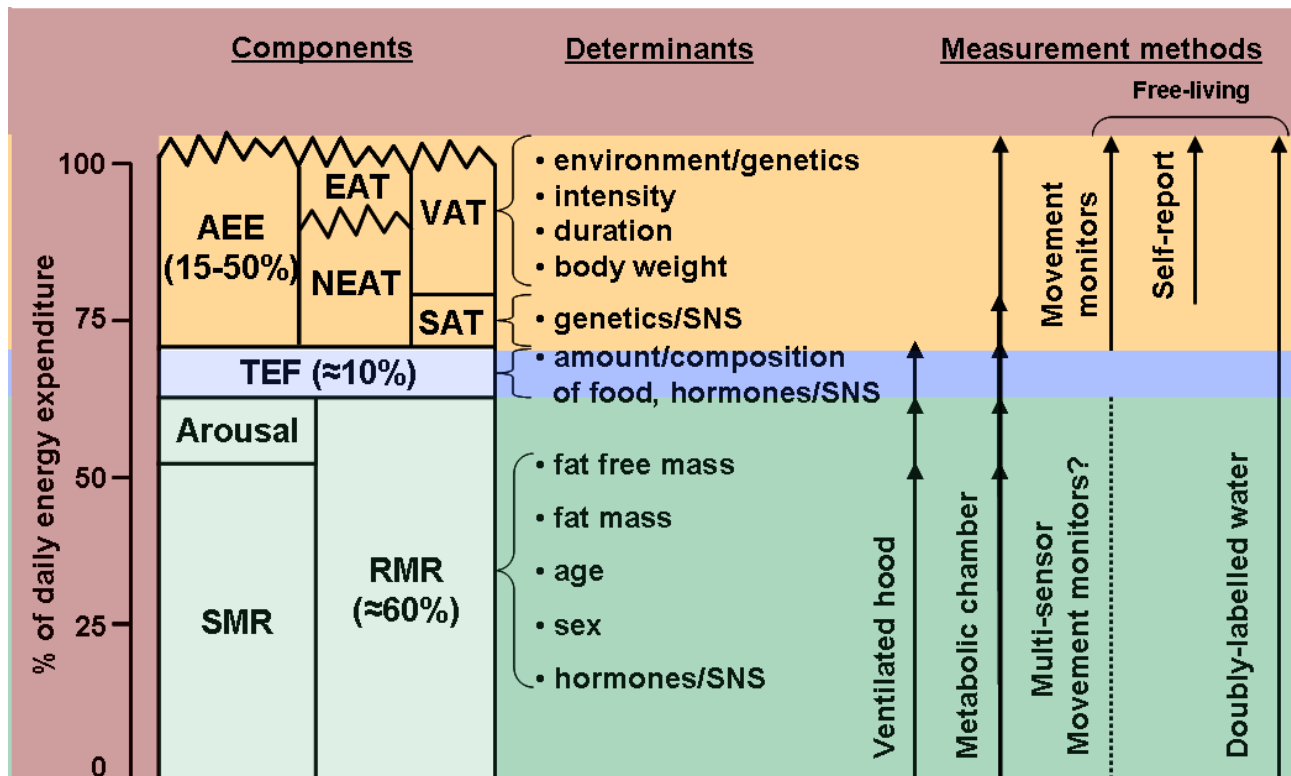


Figure 1.11. The components of daily energy expenditure, determinants and measurement methods. AEE = Activity Energy Expenditure, EAT = Exercise Activity Thermogenesis, NEAT = Non-Exercise Activity Thermogenesis, VAT = Voluntary Activity Thermogenesis, SAT = Spontaneous Activity Thermogenesis, TEF = Thermogenic Effect of Food, SMR = Sleeping Metabolic Rate, RMR = Resting Metabolic Rate (adapted from Snitker *et al.*⁵⁵³).

Basset states that PA is a “*multi-dimensional construct that includes variables such as frequency, intensity, duration and circumstance*”³⁹ (Figure 1.12). There is a qualitative or contextual aspect of PA, in other words, the situation in which the behaviour occurred and the type or mode of behaviour. The quantitative aspect refers to those elements that do not require a context in order to be measured. These elements occur irrespective of the context. Admittedly, physical activity is a behaviour and as such frequency, duration and intensity can also be seen as behavioural characteristics.³⁸⁷ However, it does not automatically follow that these behavioural characteristics are purely qualitative aspects because the characteristics are quite naturally expressed in measurable units which can be deduced from the signal patterns recorded by objective measures. Current measurement technology cannot yet cross the contextual divide, although there are attempts at this,^{490,564} which is why self-report instruments are still very much an integral part of Physical Activity Epidemiology. The quantitative aspects often have to be tied to the context

within which the behaviour occurs. For instance, the discussion around NEAT^{358,363} hinges around this very aspect; is the PA and consequent EE occurring within the exercise or non-exercise context?

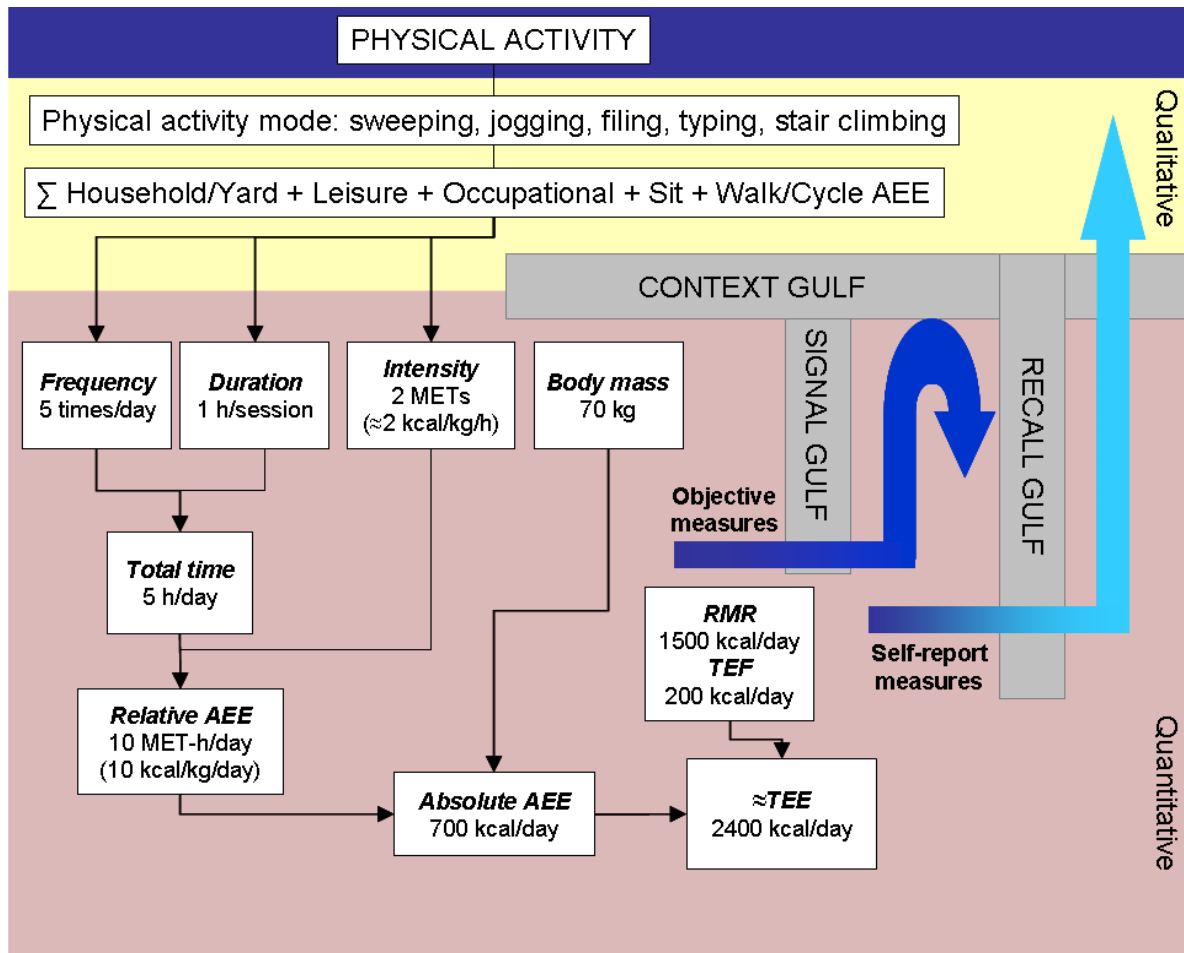


Figure 1.12. Computation of summary estimates of physical activity and total energy expenditure. RMR = resting energy expenditure, TEF = thermic effect of feeding, AEE = energy expenditure due to physical activity, TEE = total energy expenditure (adapted from Matthews³⁸⁷ and Kriska and Caspersen³¹⁹).

Certain broad contexts can be quite accurately discerned such as sitting or lying versus standing versus movement with technology such as inclinometers and accelerometers,^{255,409} walking versus running using statistical processing of accelerometry data,¹⁴⁵ or walking profile (continuous/discontinuous, speed, duration) using individual calibration.⁵⁴² Estimating activity mode requires more sophisticated approaches, not yet in general practice, such as pattern recognition, statistical methods and neural networks.^{490,564} Using remote sensing devices such as Global Positioning Satellite System data loggers also add a level of contextual information

to accelerometry data.^{375,526} With objectively-measured PA, the signals differ between instruments such that some instruments provide a delayed response to the behaviour (heart rate) and differing accelerometer count cut-points have a substantial impact on intensity^{374,388} and frequency classification.³⁸⁵ In other words, how accurately, can the quantitative aspects be classified with the signal that the instrument provides?⁵²⁹

The association between objectively-measured PA and DLW measures is quite variable because not one single instrument can account for all movement patterns and hence AEE.⁶⁷⁴ Movement counts from uni-axial accelerometers generally explain less of the variation in DLW measures than multi-axial accelerometers, and especially so compared with multi-sensor instruments.^{489,673,674} At group level, HR monitoring, specifically the flex-heart rate method, provides relatively accurate estimations of TEE.^{672,674} Using multiple sensors⁵⁷⁶ and novel combinations of subjectively- and objectively-measured PA,⁶⁸⁷ increases measurement accuracy of AEE and DLW TEE, respectively. These studies^{576,687} highlight the importance of careful selection of PA measures to cover the total PA spectrum as accurately as possible.

On the other hand, because self-report data is filtered through cognitive aspects such as perception, interpretation and memory, considerable error can occur at the group and individual level,⁶⁷² although certain contextual aspects are more accurately reported. In other words, “did I walk, run or cycle today?” and “where did I walk, run or cycle to or from?” are more accurately answered compared with “how often, how intense and how long did I walk, run or cycle today”.³⁸⁷ If self-report instruments probe as much of the PA spectrum as possible (household, leisure occupation, transport) the associations with DLW measure are surprisingly high⁶⁷⁴ although few such self-report instruments are available.⁴⁴⁵ Researchers need to carefully consider a number of factors⁶⁵⁸ before deciding on an appropriate method (Table 1.5).

A number of detailed texts^{86,279,342,426,660} and conference proceedings^{425,477,650,683} have comprehensively reviewed and described the application and scoring, design and operation, validity and reliability, advantages and disadvantages of the various types of PA measures that are available to researchers. A recent review from the European Association of Cardiovascular Prevention and Rehabilitation provides a useful, succinct analysis of the various PA measures, their validity, appropriate use, and strengths and weaknesses.⁶⁵⁸ An online resource^{iv} funded by the United Kingdom Medical Research Council also provides detailed guidelines for the appropriate use of PA measures.

Table 1.5. Ranking of methods for the assessment of physical activity on six different parameters.

	Subject interference	Subject effort	Contextual information	Activity structure	Objective data	Observer/time cost
Behavioural observation	5	1	1	2	4	5
Questionnaires diaries interviews	4	5	2	4	5	2
Heart rate monitoring	3	4	4	3	3	3
Motion sensors	2	3	3	1	2	1
Doubly-labelled water	1	2	5	5	1	4

1= highest, 5 = lowest, reproduced from Westerterp⁶⁷²

1.5.2. Physical Inactivity and Sedentarism: definitions and methods

Pate makes a most important point that when discussing PA categories, great care should be taken to differentiate clearly between terms such as PI, sedentary behaviour and insufficient PA.⁴⁷² All too often the sedentary group includes individuals in whom insufficient moderate or vigorous PA has been measured.⁴⁷² PI does not necessarily imply that no movement has occurred and some definitions can include light PA.^{103,156} Furthermore, under such a definition it does not follow that there are no positive health effects with light intensity PA.⁴⁶² Fifteen years ago Dietz cautioned that PI is not simply the opposite of physical activity, these are independent entities, and defined PI as sedentarism; *“inactivity represents a state or behavior for which energy expenditure approximates resting metabolic rate”*.¹⁶⁰ On the basis of the conceptual understanding of physical activity,³³⁵ others are not in agreement and argue that *“the terms sedentary and physically inactive (or sedentarism and physical inactivity) are not synonymous and should not be used interchangeably. The term*

^{iv} Diet and physical activity measurement toolkit: <http://toolkit.s24.net/index.html>

*inactive describes behaviour, not people...unless people are totally bedbound or otherwise restrained..., they will engage in some form of physical activity to some extent during their waking hours.. In fact, someone can spend much of their time engaged in inactive pursuits and still not be sedentary. For instance, a student who regularly goes for a run could hardly be considered sedentary, even though she may spend most of her time riding on the bus, sitting in lectures, studying and watching television..”*⁶²⁹ However, participating in a bout of PA, complying with PA guidelines or HEPA, and then spending the rest of the day in physical inactive behaviours does not necessarily constitute classification as being physically active. More recently, sedentarism is defined as “*sedentary behaviors which include sitting during commuting, in the work place, the domestic environment, and during leisure time. Sedentary behaviors such as TV viewing, computer use, or sitting in an automobile range from 1.0 – 1.5 METs. Thus sedentary behaviors are those that involve sitting and low levels of energy expenditure*” and recognises that there are accompanying negative metabolic consequences.⁴⁶²

Sedentary behaviour such as television watching, computer use, car use is usually probed using self-report instruments.^{174,175,304,659,678} Recently, the use of objectively-measured PA, specifically accelerometers,^{266,267,393} associated data reduction procedures²⁶⁵ and inclinometer technology^{255,409} have advanced the study of sedentary behaviours to the point where some have suggested a sub-specialization within Physical Activity Epidemiology; “*Science and Sedentary Behaviour*”.⁴⁶² These pioneering accelerometer studies demonstrated that using a pragmatic cut-point of $<100 \text{ counts.min}^{-1}$ as a measure of sedentary time, is independently associated with waist circumference, a host of cardio-metabolic markers and a clustered metabolic syndrome score adjusting for a number of confounders including moderate-to-vigorous activity.^{266,267} An important point is that self-report measures of sedentary behaviour have typically focussed on media use such as television viewing and computer use and as a result the estimation of the amount of sedentary behaviour is substantially underestimated.³⁹³ However, a recent review recommends that both subjectively- and objectively-measured PA are used for the population-based

monitoring of sedentary behaviour such that important contextual, time and pattern aspects are probed.²⁶⁴

Objectively-measured PA estimates in an EME suggest that $\approx 55\%$ of the populations waking hours (7.7 hr.day^{-1}) is spent in sedentary behaviours, and is even higher in older adolescents and older adults ($\approx 60\%$, 8 hr.day^{-1}).³⁹³ A more recent and innovative development is to consider how sedentary time is accumulated; a single prolonged sedentary bout or a number of sedentary bouts interspersed with breaks of activity.²⁶⁵ Independent of total sedentary time and moderate-to-vigorous activity, there are significant associations and trends ($p < 0.03$) between the total number of breaks or quartiles of sedentary breaks in sedentary time and waist circumference, BMI, triglycerides, 2-hr plasma glucose and C-reactive protein.^{265,266} Technological innovations now include inclinometers together with accelerometry such that lying down and sitting (sedentary behaviours) can be distinguished from standing.^{255,409,409} The recent work using objectively-measured PA to highlight the independent importance of sedentary behaviour in terms of CDL risk is motivated by the novel, groundbreaking work of Hamilton and colleagues^{67,248-251,693} suggesting a productive new direction of enquiry namely "*Inactivity Physiology*" with its own distinctive biological pathways, separate from Exercise Physiology.

1.5.3. History of Physical Activity measurement in Africa

Other than standard surveillance tools such as the IPAQ²⁴⁰ and GPAQ,^{241,369} which have been used locally and continentally, a number of PAQ have been adapted for use in South African studies and include a modified IPAQ,⁵⁹⁴ the Stanford Seven Day Physical Activity Recall,^{365,573} the Baecke Questionnaire,^{322,323} and the Historical Lifetime Activity Questionnaire⁴¹⁷ for adults. The CDC Youth Risk Behaviour Surveillance System Questionnaire,¹⁹ a Previous Day Physical Activity Record (PDAPR)³⁷⁹ and Physical Activity-Inactivity Questionnaires (based on the Modifiable Activity Questionnaire for Adolescents²) over a period of seven days^{408,411,416,418} and over the past year^{411,418} have been used in children and adolescents, and the Yale Physical Activity Survey for Older Adults.¹¹² Within the broader African context, the Sub-Saharan Africa Activity Questionnaire,⁵⁵⁴ a derivation of the PAQ developed

for probing PA in Pima Indians,³¹⁸ has been successfully implemented in adult populations in West Africa,^{208,555,556} and a modification of the MOSPA (MONICA Optional Study of Physical Activity)⁴⁷⁸ has provided intriguing data from East Africa.^{399,400} A Previous Day Physical Activity Record and one-week recall has also been used in Mozambican child populations.⁵⁰⁶⁻⁵⁰⁸

The lack of nationally representative PA data and high uncertainty of the PI estimates, particularly for Africa and South Africa, was noted in the GBD Study.¹⁰³ It was suggested that the lower than expected contribution of PI was possibly due to the difficulty in measuring this exposure variable. Intriguingly, Ezzati *et al.* suggest that the inclusion of PA domains common in rural DME populations (occupational and active transportation) over and above leisure activities might also explain the lower than expected contribution, especially in Africa.¹⁹⁹ From a local perspective, concerns have been raised regarding self-report data collected in rural Africans, such that PA is underestimated.¹³⁰ Even with more recent nationally representative data, concerns have been raised regarding numeracy skills, estimation of PA duration, interpretation of questions by respondents, the understanding of PA intensity and climate when collecting PA data through self-report measures.^{240,300}

Initial objectively-measured PA studies in Africa starting in the 1950's made use of time-motion, factorial methods coupled with direct measurement of the energy cost of activities using Douglas collection bags and wet chemistry methods to determine the energy cost.²¹¹ Later studies used Max Plank or Kofranyi-Michaelis respirometers¹⁷⁹ to collect gas samples and electronic gas analyzers to determine gas fractions.^{73,74,205} The MRC Dunn Nutrition Unit, University of Cambridge, England pioneers in the use of DLW⁵⁰³ and the flex-heart rate method^{109,367,559} arguably initiated the second phase of objectively-measured PA studies in Africa in the 1980's which included DLW⁵⁴⁷ and HR monitoring (Gambia, n = 8 to 37).^{268,269} The beginning of the 2000's saw the third phase of objectively-measured PA studies which used primarily accelerometry in small (n=30 to 172) West African, Senegalese samples.^{58-61,224,225,444} Since 2008 a number of studies have been conducted in East Africa (Kenya),¹¹⁹ Central/West Africa (Cameroon)^{29,31,32} and sub-Saharan Africa

(Mozambique)⁵⁰⁷ using accelerometry or a combined heart rate – accelerometer unit. Two of these studies were adult surveys (n = 552 to 1459)^{31,119} and one study was a smaller child-adolescent study (n=256).⁵⁰⁷ This last phase has been characterized by an ≈10-fold increase in sample size and the use of more sophisticated multiple-monitors. Although a number of DLW studies have been conducted in Africa since 1989,^{166,171} it is only recently that DLW-measured AEE has been shown to be significantly, negatively associated with a blood glucose concentration 2-hr post-load, even after multivariate adjustment.³⁰ Validation of self-report instruments in Africa, of which there have been few studies, have employed flex-heart rate,³³¹ HR monitoring^{134,506,554} and accelerometry.^{134,141,554} No objectively-measured PA survey studies have been done in SSA and very few studies have been done even in Africa which address methodological aspects of objectively-measured PA relevant to African settings.²⁹

1.5.4. Subjective measures of Physical Activity

Self-report PA measures form the core of population-based surveillance initiatives because of the general suitability for all populations, low respondent burden, ease of data collection and analysis, low cost and capturing of quantitative and qualitative information⁶⁵⁸ but having an emphasis on a categorical classification (inactive/insufficiently active/active) rather than creating a continuous PA variable.⁴⁸ Surveillance instruments used in large population-based samples appear to be able to detect differences between EME and DME for PA domains such as leisure, occupation and transport²⁴¹ which would underscore the observation of Baranowski as to the “*robustness of the phenomenon*” with regards to the quantification of PA.³⁶ However, using surveillance instruments in small samples and expressing the results as a continuous measure,²³⁹ compounds the high variance already inherent in surveillance instruments resulting in under-powered studies.⁴⁸ Only recently, have national, surveillance PA data been collected via self-report measures in South African youth⁵¹⁶ and adult¹⁵⁶ populations. However, national health surveys in North America and Europe which have included objectively-measured PA as part of the data collection process have highlighted a number of important discrepancies between subjectively- and objectively-measured PA, which underscore the difficulties with interpreting self-report data.^{246,259,393,519,606,613} The objectively-measured PA

results from the Canadian Health Measures Survey (2007-2009) estimated 15% of Canadians met accumulated 150 min of moderate-to-vigorous PA per week¹²⁶ which is in contrast to the 65% estimated from self-report measures.¹⁰¹ Child and adult national adherence to HEPA can be ~15-fold lower,^{519,606,613} time spent in sedentary behaviours 2-fold higher,³⁹³ and no difference in child and adolescent PA between socio-economic groups⁵¹⁹ when using objectively-measured PA. Disparities have also been found between subjectively- and objectively-measured PA across race/ethnicity because OPA was not probed in the self-report measures,^{246,259} and across educational attainment the differences in regular PA was less, although the amount of inactivity between methodologies was similar across educational levels.²⁴⁶ The disparities remained even though lower accelerometry cut-points were employed^{246,259} compared with the initial report.⁶⁰⁶ In fact, self-report measures might be more attuned to quantifying the perception of PA rather than the actual PA, hence the need for objectively-measured PA to highlight such discrepancies.⁵¹⁹

Compared with objectively-measured PA, self-report measures overestimate moderate-to-vigorous PA by 112 min ($p < 0.01$) in children,⁴⁷ and moderate and vigorous PA by 596 and 178 min.wk⁻¹ for adolescents, respectively.⁵⁵² In adults, moderate, vigorous and moderate-to-vigorous PA is overestimated by 107 min.wk⁻¹, 169 min.wk⁻¹, and 25.9 min.day⁻¹, respectively^{193,552} and self-reported distance walked is under-reported by 2.5 to 3 km.⁴² Furthermore, self-report measures over-report sitting and vigorous PA, the higher the self-report score the greater the discrepancies,²⁴³ and 50% erroneously report meeting PA recommendations as a results of overestimating vigorous and walking PA.⁵³² Almost 7% of young men reported high PA levels (upper 20%, total MET.min), but scored of the lowest physical fitness scores.²⁰⁷ The over-reporters also tended to be older, abdominally obese, smoked more, and had a lower educational level.²⁰⁷ objectively-measured PA and exercise capacity is also more strongly associated with cardio-metabolic risk factors than self-report measures.^{197,536} Just how much uncertainty is associated with self-report estimates? For instance, if an individual accumulates on average 469 min of objectively-measured PA -assessed daily total activity over one week, the self-reported total PA time could range from 174 to 3234 min.³⁶⁸ Similarly, an average

daily sedentary objectively-measured PA -assessed time of 619 min relates to a likely self-reported range estimate of 560 to 1581 min per day. Lastly, a weekly average of 9 bouts (≥ 10 min) of objectively-measured PA -assessed moderate-to-vigorous activity could result in a self-report estimate between 7 and 21 bouts per week.³⁶⁸ Although the mean bias between the subjectively- and objectively-measured PA score can be relatively small, the large limits of agreement suggest that at the population level an approximation of PA can be obtained, but classification of the individual in terms of type, intensity and amount of PA is problematic.³⁶⁸

Factors such as the interpretation of questions, the understanding of PA intensity, climate, memory storage and retrieval, judgement formation, response editing (social desirability) and time concept complicate the use of self-report questions across countries and cultures, increasing the possibility of over- or under-reporting.^{6,48,84,296,317,317,387,400,432,446,475,596,657} It is critical that in the development of self-report measures^{216,217} use is made of cognitive-based methods and memory aids to improve recall^{137,178} and that interviewers are well trained in these methods.²¹⁶ Moreover, close attention must be paid to content-related or construct evidence of instrument items.⁴⁷⁴ Arguably, the lower reliability, concurrent and criterion correlation coefficients for the IPAQ in rural samples (0.25 to 0.66) is likely as a result of a number of the above complications, which were not adequately addressed during the design the IPAQ, especially in rural DME settings.¹⁴¹

There have been few rigorous validation studies for self-report measures that purport to measure AEE by probing all PA domains and most have either a relatively weak association with gold standard measures (doubly labelled water) or not used an appropriate criterion and many self-report measures underestimate AEE.⁴⁴⁵ The development of self-report measures that can account for household, care-giving and occupational activities, and especially so in women,³⁰¹ are a relatively recent phenomena.^{11,113,216} For instance, 63.8% of urban Chinese women, 40-70 yr of age, met current HEPA (150 min.wk⁻¹, moderate-to-vigorous activity), excluding housework. However, leisure PA contributed only $\approx 10\%$ to the total non-OPA.³⁰¹

Daily walking, commuting and housework were the main contributors.³⁰¹ North American women from minority groups spend 90 min engaged in moderate intensity activities on days when at least 30 min of accumulated moderate intensity PA reported. Of the 90 min, 70% (63 min) is spent in household/yard- and occupational-related activities, while only 30% (27 min) is spent in activities such as walking for pleasure or exercise and activities related to conditioning.¹² The proportion of women meeting current HEPA (63% to 70%) were much higher than the compliance results from national surveys because these surveys omitted gender-related activities as part of moderate intensity PA behaviours.^{12,487} In agreement, 45.9% and 29.3% of men and women, respectively meet HEPA (≥ 30 min on at least five days a week) through leisure activities, but by including household activities the prevalence of meeting the HEPA rises to 60% and 65% male and female respondents, respectively.⁷⁷ However, the concern is that although many household activities are rated at >3 METs, much of the time is at lower intensities, such that the $\geq 60\%$ prevalence is an over-estimate.⁷⁷ Excluding OPA in a European setting reduced compliance with meeting HEPA from 36% to 23% and 25% to 19% in men and women, respectively.¹⁷ More recently, self-report measures that probe a number of PA domains across the full range of intensity (light-moderate-vigorous) have been evaluated for validity and reliability in DME^{302,397,554} and EME.^{66,151,217} Some self-report measures that have been used in rural South Africa, although not evaluated *a priori* for validity and reliability but displaying good construct validity,⁵⁹⁴ have shown prevalence estimates for physical inactivity/activity that are more congruent with preliminary rural objectively-measured PA estimates¹³⁰ than national estimates for rural and non-urban settings.¹⁵⁶ Because self-report measures will likely remain the instrument of choice for large, continuous population-based surveys, it is essential that as much information regarding all PA domains be available since it is the total amount of PA and sub-domains of PA that are being eroded through the Physical Activity Transition.³⁰¹ Consequently, valid, robust and reliable self-report measures that will include sedentary, exercise and non-exercise domains are urgently required, especially in DME as communities move through the epidemiological transition.

1.5.4.1. Possible solutions for rural settings – lessons from Nutritional Epidemiology

Recently, the concurrent application of energy intake and energy expenditure recall for items over a usual day were collected in over 500 rural and urban Ethiopian adults.⁵⁸⁹ Through trained fieldworkers, participants provided a chronological list of activities undertaken throughout a usual day from the usual time to they got up to the time they usually went to bed. From physical activity compendiums energy costs were assigned to each activity, and coupled with the duration of the activity, the EE was calculated (Figure 1.13A). Although the concept of measuring energy intake and EE concurrently is not novel in Africa^{73,205,540} and other DME,⁴⁷⁵ the authors have highlighted a less laborious, and more practical methodology for contemporary DME, which should be considered by researchers and health agencies concerned with tracking the changes in energy intake and EE due to the Physical Activity Transition. The study was novel from a DME perspective in its data analysis that allowed for the identification of energy intake misreporting, the classification of the population into lifestyle activity categories (sedentary, light, moderate, vigorous) and although not done in the analysis,⁵⁸⁹ the classification of activity in terms of activity domains (Figure 1.13A and 1.13B).⁵⁸⁹ Such analyses are particularly relevant when tracking changes in the proportion of time and energy spent in more sedentary to light activity domains due to the Physical Activity Transition.³⁰¹ Importantly, because of the difficulty in assessing light activity the use of short recall periods (1-3 days) might be more valid.³⁹⁰ Similarly, Western Samoan men recalled their energy intake, as they proceeded through a 24-hr PA recall, producing data similar to that in Figure 1.13B.⁴⁷⁶

Using multiple 24-hr PA recalls Matthews *et al.* have investigated the sources of variance³⁹⁵ and seasonal variation³⁹⁴ in an EME setting for total, occupational and non-occupational activity domains. Such short-term activity recalls correlate well with questionnaire and accelerometry data (median: $r=0.60$, range: $r=0.16$ to 0.92).³⁹¹ Data collected with tools such as the Sub-Saharan Africa Activity Questionnaire and Previous Day Physical Activity Record also enable the researcher to conduct activity domain analyses.^{208,323} Furthermore, such approaches are theoretically sound as

multiple time and context anchors are provided,⁴⁷⁵ improving the accuracy of the recall.

Taking this approach one step further, it is also possible to construct an Activity Frequency Questionnaire,^{63,77,562} analogous to the data-based approach to construct a Food Frequency Questionnaire.^{75,76}

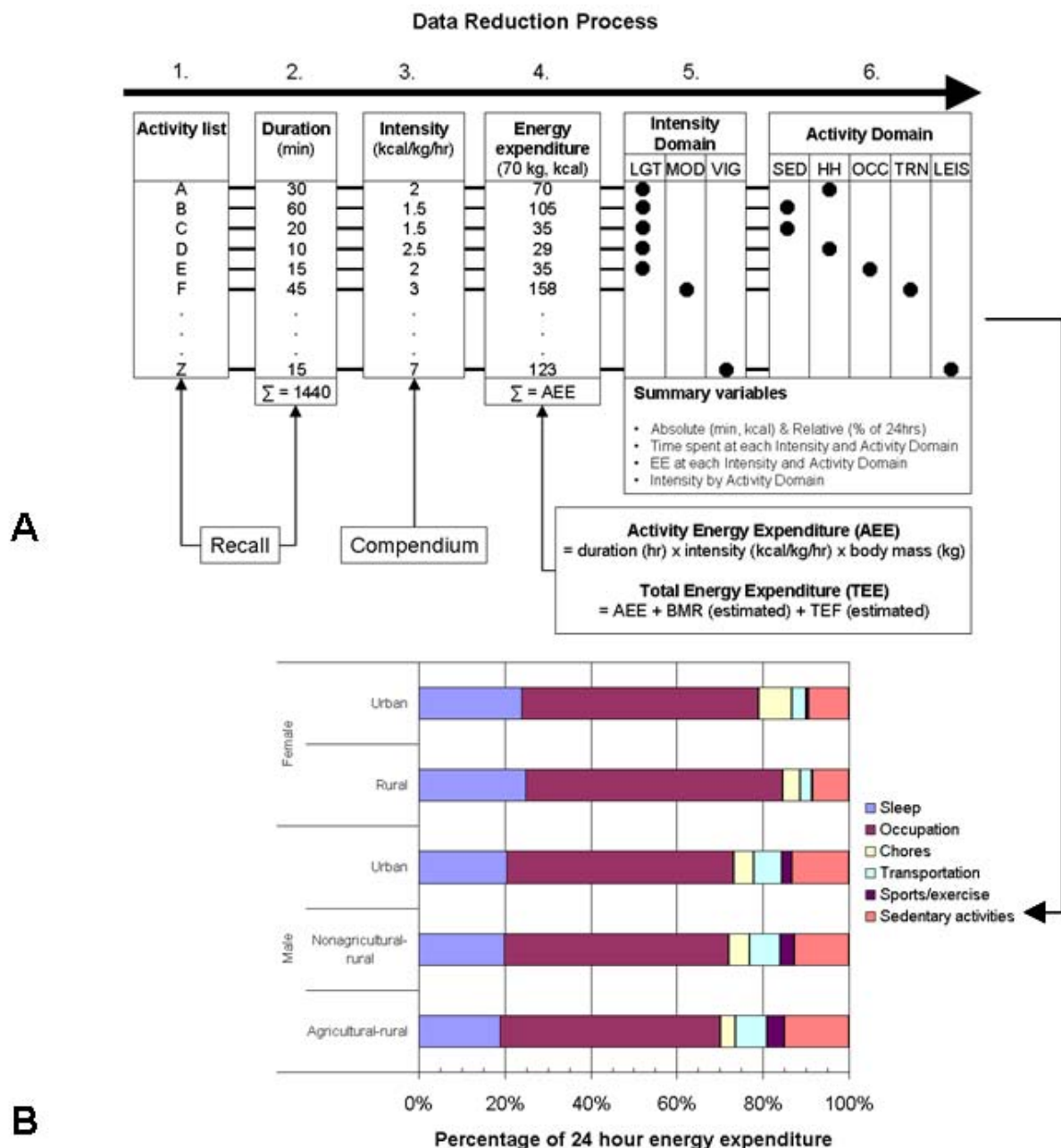


Figure 1.13. Conceptual data reduction process of a 24-hr activity recall tool (A) and an example of how processed data can be used to quantify the relative energy expenditure across gender, occupation and residence (B). Figure B constructed from data in Gregory *et al.*²³⁷,

LGT = light, MOD = moderate, VIG = vigorous, SED = sedentary, HH = Household and yard, OCC = occupation, TRN = transport, LEIS = leisure.

The initial effort consists of determining, from a large enough sample, the principal activities that account for 95% of the population, and separately 95% of male and female activities, EE.⁶³ In addition, those activities that account for 10% or more of an individual's EE are also included.⁶³ From a South African perspective, Kruger *et al.* validated an adapted Baecke PAQ for a black African population in a pilot study by listing all the activities performed in that study population.³²² The activities were then categorised under occupational, commuting, stair climbing, sports, and leisure-time PA. This has allowed for categorization of important PA categories,³²³ but instead of using MET values for the activities to calculate an estimated EE, a unit-less physical activity index was calculated, making it difficult to reconcile to PA guidelines.³²² The efforts of this research group have shown that a Food Frequency Questionnaire development approach is feasible and even this initial data has provided an interesting profile of PA across a number of important categories and between rural and urban groups.³²³

In EME settings, the initial interview-based 24-hr recall required to establish a representative database takes 15-20 min to complete.^{63,389} A self-administered Activity Frequency Questionnaire can take 12-20 min to complete,^{63,77} but longer if integrated with a Food Frequency Questionnaire and interviewer-administered,^{476,589} especially in rural areas, where recall aids would most likely be required, specifically for time-related aspects of the Activity Frequency Questionnaire.³²³ Validation studies report simple correlation coefficients of 0.63 to 0.76 between Activity Frequency Questionnaire and DLW, and an adjusted $R^2 = 0.70$ between measured TEE (DLW) and predicted TEE (Activity Frequency Questionnaire and resting metabolic rate).⁵⁶² Similarly, correlation coefficients between the EE estimated from an Activity Frequency Questionnaire, 24-hr recall and the flex-heart rate method ranged from 0.55 to 0.80.⁶³

Using standardized methodologies to construct and score the Activity Frequency Questionnaire should provide directly comparable outcome measures in continuous

and categorical format, such that meaningful analyses can be conducted across gender, residential, ethnic and socio-economic strata, in far greater detail than is currently possible with surveillance instruments such as the IPAQ and GPAQ. Moreover, Activity Frequency Questionnaire, as with Food Frequency Questionnaire,⁵⁹³ should also be robust and sensitive enough to track changes in population PA behaviours and thus provide more definitive data as to the progression along the Physical Activity Transition³⁰¹ of a community or population.

1.5.5. Objective measures of Physical Activity

In 2000 Wood concluded that objectively-measured PA is *“relatively expensive and therefore not practical for large-scale studies, ...prone to instrument malfunction”*,⁶⁸³ but only six years later Janz suggested that the gap between the accuracy of objectively-measured PA and the feasibility of assessing free-living PA has narrowed considerably, such that movement monitors could be viewed as the expected means for PA quantification in small to medium sized studies.²⁹² Recently Bauman *et al.* emphasized that *“To minimize the concerns regarding use of self-report measures for surveillance, alternative approaches, including the use of objective population measurement for international comparison and surveillance should be pursued, especially in developing countries”*.⁴⁸

From an EME perspective, Katzmarzyk and Tremblay highlighted the secular decrease in self-reported leisure-time PI yet an increase in the use of household devices associated with sedentary behaviour and an increase in the prevalence of PI-related diseases.³⁰⁷ If these trends are correct, the implication is that NEAT-induced EE, which makes up the major portion of total EE, is declining. It would seem then that a focus on threshold-type guidelines do not consider total PA and as such a total EE might be declining in a population yet a greater proportion of individuals are achieving the required threshold.³⁰⁷ Indeed the paradoxical findings of relatively similar PA threshold prevalence results for 22 African countries compared with results from EME would appear to support this concern.²⁴¹ Moreover, inconsistent self-report methods and response and respondent biases allows for misinterpretation and misrepresentation of data.³⁰⁷ Consequently, Katzmarzyk and

Tremblay enlightening conclude that, *“The health outcome data strongly suggest that our current physical activity monitoring systems [exclusively self-report measures], and the trends they have produced, **deviate from reality**,... perhaps progressively, masking more pervasive sedentarism that eludes our present surveillance systems...Further, a more robust monitoring system that includes more direct measures of physical activity is required for an accurately informed policy and a correct understanding of relationships between physical activity and the risks of developing various chronic diseases.”*³⁰⁷ The implications for rural DME settings are similar. At present in some settings a high NEAT drives a high total EE, but this is not detected by current self-report instruments and the population is categorised as less active than is the case. Over time, NEAT-induced EE declines rapidly but the current surveillance instruments will not detect these changes. Consequently, it is likely that increases in PI-related morbidity and mortality will increase despite increases in certain self-reported PA domains as health promotion campaigns focus too narrowly on LTPA. To ensure that the NEAT changes are relatively accurately monitored will likely require a different approach to self-report measures and greater inclusion of objectively-measured PA in national surveys.

Considering the success of the objectively-measured PA arms of the NHANES Study,^{266,393,606,623} the Canadian Health Measures Survey¹²⁶ and the Health Survey of England,¹¹⁵ and the difficulties of accurately assessing PA in rural South Africa,¹³⁰ it would seem prudent to similarly triangulate nationally-representative self-report PA data with nationally-representative objectively-measured PA data. Furthermore, because of the substantial health challenges that face DME, often as multiple burdens of disease,⁸⁹ and the limited resources at the disposal of DME government and non-governmental organizations, it is critical that any interventions are based on sound evidence. Should results from national surveillance studies not provide accurate reflections at the national and provincial level in terms of physical activity and inactivity patterns and volumes, scarce resources would be squandered. Consequently, it could be argued that considering the results from surveillance efforts in EME that have included objectively-measured PA and the availability of a host of monitoring devices, not including objectively-measured PA as part of a

national PA surveillance strategy in DME such as South Africa, is likely to result in “[in]accurately informed policy and [in]correct understanding”.³⁰⁷ The resulting PA public health policy would be divorced from reality, such that compliance with such guidelines would likely be low if the target audience perceives the message to be at odds with their environment, constraints and concerns. Ultimately, the success of an intervention judged against a goal (percentage of people active at a future date) contained within a national strategic plan would be difficult to ascertain.³⁰⁷

There are a host of objective measures that can be employed to measure PA either singly or in combination.^{489,526,543,543,576,611,660} Although subject reactivity is a concern if not guarded against,¹²¹ the use of objectively-measured PA circumvents reporting errors associated with subjectively-measured PA such as translation, misinterpretation and social desirability.²⁹² This makes it possible to more directly compare results across countries.^{54,245,640} Compliance with HEPA in terms of frequency, intensity and duration can be evaluated through both subjectively- and objectively-measured PA.^{260,431,606} However, objectively-measured PA also makes possible the measurement of numerous, relatively short duration low-to-moderate activities that occur routinely during daily, free-living PA and which are difficult to capture accurately and reliably with self-report measures.^{292,672} Yet it is precisely the accumulation of frequent, short duration, moderate activities which are at the core of national and international HEPA.²⁹² A different approach is to relate the output from pedometers, namely steps.day^{-1} ⁶²² or steps.min^{-1} ^{4,383,530,631} in terms of compliance with physical activity guidelines.^{285,339,679} Some pedometers provide readouts of the number of min accumulated in the moderate-to-vigorous intensity zone, such that both a volume (total number of steps) and intensity (time above moderate intensity) domain are captured.^{258,403} Considering the host of HEPA guidelines that exist,⁵⁹⁰ it begs the question as to what effect these HEPA would have on classifying an individual as active or inactive. In this case, the use of objectively-measured PA is essential because of the measurement accuracy required to test the classification agreement or lack thereof. Using a combined heart rate–accelerometer movement monitor, nine out of every ten men could be described as either active or insufficiently active, depending on which of the 12 PA recommendations available as

of 2009 was applied.⁵⁹⁰ Moreover, the evaluation of bouts of free-living activity as promoted by physical activity in order to accumulate the required daily dose, and the effect on health-related variables, demands the use of objectively-measured PA.^{577,675}

Dealing with measurement error is an essential analytical aspect within Nutritional⁶⁸¹ and Physical Activity Epidemiology.²⁷⁹ objectively-measured PA also provide a means whereby measurement error can be quantified and attenuation factors derived and applied to the association between self-report measures and health outcomes. Typically, smaller calibration studies are conducted within larger studies where PA is measured repeatedly using subjectively- and/or objectively-measured PA.^{204,651} Even with objectively-measured PA, estimation of the measurement error through repeated measures can yield a stronger association between objectively-measured PA and associated health outcome.^{190,213,214,651,654} Using objectively-measured PA to estimate an attenuation factor for self-report measures, would increase a measured relative risk from 1.1 to 2.0.²⁰⁴ De-attenuation does not alter the dose-response relationship between PA and health outcome, but does strengthen the existing relationship.^{583,651} Whether using repeated measures of objectively-measured PA or self-report measures (24-hr recalls), there is an urgent need to implement this methodology in DME.

The 1994 text *"Measuring Physical Activity and Energy Expenditure"* categorizes most of the objectively-measured PA as practical only within small studies ($n < 50$).⁴²⁶ While this is true of methods such as DLW, the small size, relatively low respondent burden, robustness, validity and reliability and ever-decreasing costs of objectively-measured PA such as pedometers, accelerometers and HR monitors have made it viable to use these technologies in large-scale cohort ($n > 500$) and population-based ($n > 5000$) surveys.⁶⁵⁸ Tryon states that *"the relatively low cost of high quality step counters [the same could be said for accelerometers] renders the omission of instrumented measurements regarding research on human activity **inexcusable** in any serious scientific study..."*.⁶¹¹

The Isle of Ely Young Cohort Study, situated in England and which commenced in 1994, was arguably the first in a new generation of investigations that have used objectively-measured PA to more accurately explore the relationship between PA and CDL and associated risk factors, in medium to large scale population-based studies.^{651,652,655,656} Wareham and associates assessed EE, using the flex-heart rate method pioneered by Ceesay *et al.*,¹⁰⁹ from four days of min-by-min HR in 775 adults aged 45-70 yr. The pioneering Ely Study, has arguably been progenitor to a host of medium to large scale, cross-sectional and longitudinal studies which have used objectively-measured PA in children and adolescents^{139,140,191,192,461,523} and adults,^{46,115,126,182,244,606} ranging in sample size from ≈500 to more than 10 000. The largest study to date is the Canadian Physical Activity Levels Among Youth survey that sampled 11 658 youth between 5-19 yr of age, collecting five days of pedometry data.¹⁴⁰ Substantially less objectively-measured PA data is available from DME, especially SSA, and even Africa in general. A number of small to medium scale, mainly cross-sectional, objectively-measured PA surveys, ranging in sample size from 40 to 1459 participants, have been conducted in DME and include the use of pedometers,^{24,595} accelerometers^{58,485,507,518} and combined heart rate - accelerometer units.^{31,119}

Although large scale, population-based HR monitoring, using wireless watch receivers and chest transmitter belts, has been successfully implemented in industrialised settings,⁶⁵² its use has been challenging in rural settings in Limpopo Province. In order to collect valid data from rural forestry workers, the watch receivers had to be firmly attached to the transmitter belt with elastic strapping and contact glue (Figure 1.14).^{134,136} This prevented subjects from inadvertently damaging the receiver during forestry tasks or stopping the receiver by depressing the setting buttons. However, even over a relatively short period of three to four days, subjects complained of sweatiness, itchiness and skin irritation, which was not surprising considering the high ambient humidity and temperatures to which the workers were exposed to during the course of their duties. Moreover, compared with uni-axial accelerometers (n = 59 ex 61), far fewer subjects provided valid HR data of

at least one working day ($n = 28$ ex 59).^{134,136} It is likely that the use of chest electrodes to collect min-by-min HR data would be more successful in hot rural environments^{32,92,119} or the use of shorter sampling periods e.g. 24 hr.⁵⁵⁴



Figure 1.14. Placement of movement monitors on rural forestry workers.^{134,136}

In contrast to continuous, min-by-min HR monitoring over several days, the collection of HR, with the same wireless technology, during a fitness test^{254,320,545,546} would seem feasible to implement in a rural setting such as the Dikgale Health and Demographic Surveillance System site (DHDSS).^{13-15,131} A low exercise capacity determined from physical fitness testing and low EE estimated from self-report measures is associated with higher mortality risk, more so than that of traditional risk factors such as smoking, hypertension, diabetes, previous CVD.⁴⁴¹ Indeed, exercise capacity is a stronger predictor of all-cause mortality than EE estimated from self-report measures.⁴⁴¹ Exercise capacity modifies the relationship between EE estimated from objectively-measured PA and the metabolic syndrome such that the

association between PA and the metabolic syndrome is much steeper in unfit individuals.²¹⁴ Consequently, if at all feasible, appropriate physical fitness testing should be conducted together with PA measurements during any population survey.

A good example of this approach is the recent Health Survey of England conducted in 2008 which included self-report measures, objectively-measured PA and exercise capacity testing^v. Other measures which could also be collected during a fitness test include recovery HR and heart rate variability,³²⁹ both of which are related to an increased risk of morbidity and mortality.¹⁵⁰ Evidence suggests that in comparison with gold standard heart rate variability measures, commercially available HR monitors and accompanying software are sufficiently accurate for initial screening and as such for use in community-wide surveys⁵¹⁰ although there are concerns regarding reliability.^{455,455}

Taking into consideration the cost of combination sensors such as the Actiheart,⁶⁵⁸ the greater amount of ambulatory activity present in rural DME settings,^{400,555,645} the lower costs, proven track record in large cohorts, reliability and validity studies, and the availability of open source data reduction software,⁶⁵⁸ it would appear that accelerometry and pedometry^{138,629} would be well suited to rural DME settings such as DDHSS.

1.5.5.1. Accelerometers

The introduction of accelerometers as a viable method within Physical Activity Epidemiology was ultimately dependent on advances in microchip technology during the 1970's. For the period 1980-1989 only 9 references for the keywords "accelerometer" or "accelerometry" and "physical activity" could be traced within the title and abstract. This increased to 92 for 1990-1999 and to 1031 for 2000-2009. This simple exercise^{vi} illustrates the remarkable, exponential increase⁶⁰⁴ in the use

^v The survey results and detailed methodology can be obtained online; <http://www.ic.nhs.uk/pubs/hse08physicalactivity>.

^{vi} <http://highwire.stanford.edu> including PubMed

of accelerometry within the field of Physical Activity Epidemiology. The large scale surveys in EME ^{115,126,606} mark the beginning of a new era wherein objectively-measured PA use within national surveillance systems will be considered mandatory for the realistic interpretation of self-report data.^{48,307} However, compared with EME settings, very little has been published for accelerometry in DME, especially so for Africa.^{29,58,136,168,224,225,507}

Chen and Basset define accelerometers, of which there are a number of commercially available units on the market,^{426,611,661} as “...*devices that measure body movement in terms of acceleration, which can then be used to estimate the intensity of PA over time. Most accelerometers in current use are piezoelectric sensors that detect acceleration(s) in one to three orthogonal planes (anteroposterior, mediolateral, and vertical). Processed data can be recorded by internal memory and then downloaded through computer ports*”.¹¹⁶ The most popular unit to date is a uni-axial accelerometers (CSA/MTI/ActiGraph) which has proved it's robustness ^{115,606} and has been extensively validated using DLW.⁴⁸⁹ In 2004 a scientific meeting “*Objective Monitoring of Physical Activity: Closing the Gaps in the Science of Accelerometry*” addressed issues around implementation, data analysis, calibration and technology, of specifically the ActiGraph accelerometer.⁶⁰⁴ The resulting supplement published in *Medicine Science in Sports and Exercise* 37(11): S487-S558, is a landmark objectively-measured PA publication for researchers in Physical Activity Epidemiology. Because accelerometry produces extensive and complex data, open source ^{vii} and commercial ^{viii} software are available for data reduction. The greater validity, reliability and robustness of hardware and readily available software capable of dealing with the veritable mountain of data that a single unit can produce, has made the use of accelerometry even more accessible to researchers in the field of Physical Activity Epidemiology.

^{vii} *Mahuffe*: available at <http://www.mrc-epid.cam.ac.uk/Research/PA/Downloads.html>

^{viii} *MeterPlusTM*: available at <http://www.meterplussoftware.com>

A limitation of uni-axial accelerometers is that the unit is typically worn at the waist and does not always accurately capture upper body movements and any other movement where there is no appreciable vertical acceleration (cycling, rowing, incline walking, carrying a load). However, uni-axial accelerometers are more accurate for measuring ambulatory activity^{147,338} but because of the lower sensitivity threshold more non-step movements are erroneously detected (motor vehicle travel).³⁴⁰ The signal processing algorithms of some uni-axial accelerometers make the units less prone to false positive readings.⁴⁰² There is a very high association with EE measured in highly controlled environments ($r=0.91$),²¹⁵ but this becomes challenging in free-living environments.¹⁴⁴ In contrast, there is a tight association ($r\geq 0.90$) between uni-axial accelerometers counts and level walking speed in free-living environments.³⁸ Because of the lack of data from DME, specifically Africa, four aspects that are of particular interest and require investigation include reliability, unit placement, valid cut-points for data reduction and using accelerometer data to investigate NEAT and establish PAQ validity. The latter aspect has been reported elsewhere,^{78,134,141} although it would prove useful to determine if a PAQ could be developed from constructs related to NEAT.

Numerous studies in EME settings have investigated the reliability of objectively-measured PA free-living physical activity.⁶⁰⁷ However, few papers have reported sources of variation for either subjectively-³⁹⁵ or objectively-measured PA.³⁹⁰ Within the South African context there is a dearth of reliability studies for any form of physical activity assessment.^{78,134,141,322} The reliability of objectively-measured PA under free living conditions in South African samples has not been reported. Moreover, no data has been reported regarding the sources of variation for any type of PA measurement instrument in South African samples.

To date a number of laboratory-based studies have considered the effects of different placement positions on the output of uni-axial accelerometers⁶⁰⁷ and the intra- and inter-instrument variability of uni-axial accelerometers using mechanical settings^{93,414} or motorised treadmill trials.^{531,666} Few studies have employed free-living protocols when evaluating the effect of placement position of movement

monitors or the inter-instrument reliability of movement monitors.^{404,689} Only one free-living study has considered the placement position of uni-axial accelerometers.⁴⁰⁴ That study was carried out in a highly urbanised setting, during the waking hours of one highly structured day, using students and staff from a university setting who were recreational runners and accumulated significant amounts of vigorous physical activity.⁴⁰⁴ Consequently, similar and more expanded analyses of free-living samples with more variable day-to-day physical activity patterns are required. Importantly, rural subjects with low, recreational (vigorous) physical activity but high work-related (moderate) physical activity demands should be recruited.

The preoccupation with typical leisure-type pursuits in industrialized settings, has led to the adoption of accelerometer count cut-points (≥ 1952 counts.min⁻¹) which ignore NEAT activities that accumulate counts between 500 – 1000 counts.min⁻¹.^{392,472} There is a dearth of data describing PA count distribution for the SSA region,^{30,58,168,507} and specifically within the rural South African context. Only one study has reported using cut-points established for a specific DME setting.⁵⁸ Forty rural Senegalese adolescent girls had their PA recorded using min-by-min direct observation (time-motion) and uni-axial accelerometers concurrently over two and four consecutive days, respectively. This was done during the dry (n=40) and wet (n=30) seasons.⁷⁴ The time-motion data was converted to EE units using EE data available for African activities.^{74,202} From the average daily EE, determined from the time-motion data, and the average daily accelerometer count a pooled regression equation was produced relating METs to counts.min⁻¹ ($r=0.50$). From this equation cut-points for light, light-to-moderate and moderate-to-vigorous domains were established. This study was novel for a number of reasons.⁷⁴ First, popular cut-points developed in EME settings used highly controlled laboratory data²¹⁵ instead of free-living data. This study was analogous to the initial lifestyle-equations of Hendelman *et al.* ($r=0.58$) and Swartz *et al.* ($r=0.56$).^{270,581} Second, the investigators used data from African settings to estimate the EE cost of common activities. Third, the concurrent use of time-motion methods made possible the classification of PA into distinct PA categories, providing an insight into NEAT for an adolescent African sample. A more recent study, using DLW, has proposed a number of new equations

to predict AEE from accelerometer counts and other descriptive variables ($r=0.37$ to $r=0.63$).²⁹ These equations perform better²⁹ than a number of popular treadmill²¹⁵ and lifestyle equations.^{270,581} One criticism of the models is the inclusion of a residential variable (rural/urban).²⁹ As has been argued earlier, this is a crude classification and can differ widely across EME and DME settings. A more standardized and robust classification of “urbanization” must be adopted by Physical Activity Epidemiology such that it will make possible a more direct comparison between socio-economic settings and for inclusion into equations such as those proposed by Assah *et al.*.²⁹ Another solution is to use regression models based on the variation of the counts over 10 seconds, to predict AEE.^{145,148} With the enhanced memory capacity of current uni-axial accelerometers, and because open source data reduction software caters for this methodology, this option appears practical for DME settings, particularly where NEAT activities form the basis of much of the AEE. Lastly, there is good evidence to argue for a moderate threshold of 760 cts.min^{-1} ^{1,388,389,665} such that many of the subsistence or lifestyle activities performed in rural and urban settings would be assessed within the range of $500\text{-}1000 \text{ cts.min}^{-1}$.³⁹² Pate *et al.* emphasize the importance of analyzing accelerometry counts across the full range of EE rates below moderate intensity.⁴⁷² Ignoring accelerometer counts which contribute to light-to-moderate EE over extended periods of time, and concentrating solely on moderate-to-vigorous cut-points which exclusively probe bouts of activity to fulfil current HEPA can result in the misclassification of an otherwise active individual as sedentary.⁴⁷²

Data collected in the DHDSS during 1997¹⁵ included the BRISK self-report instrument,⁵⁶⁹ but which was not tested for validity and reliability, and might display a floor effect such that important HEPA behaviours were not probed.¹³⁰ For example, while moderate-to-vigorous OPA and LTPA would be probed, low-to-moderate household and yard PA would be under-reported. Consequently, any comparison with PA data collected a decade later would be meaningless, particularly because the Physical Activity Transition is eroding NEAT activities. However, more recent surveys have included the same or very similar socio-demographic variables related to transport, electricity and water supply, and the use of wood as fuel. Because the

socio-demographic data contains variables which are directly or indirectly linked to a household's subsistence level, and therefore PA level, it may be possible to construct and validate a simple Subsistence Activity Index. Such socio-economic variables affect the possession or not of a number of assets which in turn directly or indirectly decrease or increase PA behaviour and hence AEE levels. These variables do not narrowly confine their influence within a household to a small number of tasks which might affect only a few members of the household. Rather, the effect is fundamental and pervasive such that the entire household is affected in terms of PA choices and behaviours and consequent EE levels.^{57,271,336} In DHDSS households, workload is spread relatively evenly throughout the female population, unless very ill or incapacitated. The chores might not be all equal in nature, but rather that the general activity level is higher in that household, especially so for women. These subsistence tasks performed by the household are usually light-to-moderate in intensity, spread out over a large portion of the day which is in contrast to Western productivity which requires high bursts of energy over relatively shorter periods of time.⁴⁶⁹ The use of physical activity index scores has been used with some success in SSA.^{324,428,558} However, the determination of HEPA from an index is problematic. If PA is not the main factor being investigated, but is rather a covariate that must be controlled for, index scores are quite useful.

1.5.5.2. Pedometers

Also known as *Manpo-kei* or "10 000 step meter" in Japanese,⁸ pedometers have been exhaustively reviewed in terms of construction and mechanism,^{ix} validity, reliability and best practice guidelines for research and health promotion.^{44,624-627,629,630,632} Pedometers have been used successfully in large health promotion projects^{46,142} and two recent meta-analyses have reported modest reductions in body mass, BMI and systolic blood pressure ($p \leq 0.03$).^{96,522} Importantly, pedometers are an acceptable measure of total physical activity and inactivity^{350,374,664} but not EE^{327,349,350,592} because many movements do not produce significant vertical acceleration of the hips (swimming, cycling, rowing, sweeping, digging).⁵⁹² However,

^{ix} *The Anatomy of a Pedometer* at <http://www.pedometers.com>

pedometers are more accurate at estimating ambulatory EE^{147,592} and especially so when using an accelerometry signal.^{147,327}

The use of objectively-measured PA in Africa dates back to the 1800's when explorers and surveyors made extensive use of pedometers to measure the distance walked from which maps were constructed.³⁷² Some reports indicate that pedometers and perambulators or surveyor's wheels were used in tandem⁶¹⁰ predating the study of Basset *et al.* by nearly 100 years!⁴² Interestingly, the use of pedometers extends to companion animals¹¹⁰ and livestock.⁶⁴⁸ Remarkably, the oldest and smallest step integrator or pedometer, is biologic and found in the animal kingdom namely desert ants or *Cataglyphis fortis*.⁶⁸² The pedometer is capable of accurately measuring the number of steps and the distance per step. Moreover, it is used in combination with a celestial compass, which measures path direction. The input from the pedometer and the celestial compass allow these small creatures to cover distances of more than 100 m in search of food, following a meandering path out and a straight trajectory home.⁶⁸² Hence, the recent use of multiple monitors such as accelerometers, with a pedometer function, and Global Positioning System⁵²⁶ are our first stumbling efforts at an elegant and efficient design that has been present in nature since the beginning of time!

The Digiwalker spring-levered, coiled-sprung pedometers have become a mainstay as a research and health-promotion pedometer and as such have been used in numerous studies as a criterion and a survey device.⁴⁴ Consequently, for comparative purposes and sample size calculations, it is important that data be collected with these pedometers in specifically rural African settings. Because of the mechanism used, the Digiwalker cannot distinguish between a step taken during walking or running, nor is there a multi-day memory storage capacity. The Digiwalker also does not contain any signal-filtering ability such that non-ambulatory signals (vehicle travel) can be discarded, although it does have a higher specificity because of the higher sensitivity threshold.³⁴⁰ However, the Digiwalker does display the distance walked if a stride length is entered. It is this latter ability that has been examined in several studies^{41,42} and considering the difficulty in assessing

ambulatory activity through self-report measures, especially in rural African settings, this characteristic could be most useful. Although walking distance is not as accurate as steps, especially at low walking speeds, the measure is still more accurate than can be obtained with self-report measures.⁴²

To overcome the disadvantages of the Digiwalker, pedometers using a different step-sensing and signal-filtering mechanism are required. Advantages of the NL-2000, a piezo-electric or accelerometry-based pedometer, include that it accurately captures ambulatory activity at lower walking speeds of $\geq 4.02 \text{ km.hr}^{-1}$, compared with the $\geq 4.80 \text{ km.hr}^{-1}$ of the Digiwalker.¹⁴⁷ Because the NL-2000 is accelerometry-based it is also able to distinguish between the energy cost of walking and running. However, coupled with the greater sensitivity of the NL-2000, such that greater amounts of low-to-moderate ambulation can be accurately and consistently captured, the NL-2000 also contains a signal-processing algorithm in the microprocessor which filters the signal from the piezo-electric crystal in order to exclude non-ambulatory movement and thus maintain specificity.¹⁴⁹ Moreover, the NL-2000 is not affected by pedometer tilt or adiposity level.¹⁴⁶

The NL-2000 stores both the daily AEE and step count. This aspect of the NL-2000 deserves further investigation in that it might be possible to deduce intensity influences from the pedometry data and that more direct comparisons could be made with HEPA. Two novel approaches are possible. First, the AEE for each valid step is calculated using body mass (BM, kg) and an intensity dependent factor (Ka) such that $\text{AEE (kcal)} = Ka \times \text{BM}$. Thus by statistically adjusting for body mass and total steps through general linear models when examining AEE across groups, it would be possible to deduce whether an intensity or volume effect explains the differences in AEE between groups. Second, Mudd *et al.* used an AEE-based method to ascertain the compliance with HEPA.⁴³¹ This AEE-based approach utilizes units such as kcal.kg^{-1} per unit of time, and because the NL-2000 pedometer stores AEE in kcal.day^{-1} it would seem feasible to explore the possibility of adapting the approach of Mudd *et al.* to pedometer data.⁴³¹

Consequently, piezo-electric pedometers, of the quality of the NL-2000, should be the instruments of choice in rural settings such as that encountered in the DHDSS. Moreover, the current size of the DHDSS is approximately 35 000 residents which would make surveys within this rural site practically and financially feasible. Because walking constitutes much of the PA in these rural settings, the use of a high-quality pedometer such as the NL-2000 with a 7-day memory capacity would be valid, practical and cost-effective for large-scale, free-living surveys.⁵³⁷

1.6. SUMMARY OF THE LITERATURE REVIEW

Evidence linking physical activity to health dates back more than 4500 years. It is most ironic that the host of technological advancements that have made possible the uncovering of this ancient evidence is also a significant factor in the migration to the current sedentary lifestyle of modern civilization. The Industrial Revolution accelerated in the second half of the eighteenth century through innovations in the textile and iron industries and steam power. While ushering in great material wealth for EME, these innovations did not immediately reduce activity energy expenditure. To the contrary, working conditions were lamentable comprising long working hours. Industrial and societal reforms coupled with further innovations eventually resulted in a reduction in activity energy expenditure, principally in the occupational domain. The first micro-processors produced in the 1970's ushered in the Information, Computer or Digital Age. The further reduction in occupational physical activity has accelerated since the 1950's. Coupled with the deleterious changes in the built and food environments, the reduction in activity energy expenditure is strongly implicated in the inexorable rise in overweight and obesity levels in EME. The more recent accelerations in adiposity levels and associated morbidity and mortality in DME are potentially far more serious than that experienced by EME because of the greater population sizes, reduced capacity to deal with the diseases of lifestyle and associated risk factors and multiple, concurrent burdens of disease. Attempts to correct the resulting energy imbalance through increasing leisure-time physical activity, particularly in EME has not been consistently successful, and continued efforts in this regard are likely to be futile. Rather, the large reduction in NEAT should

be addressed together with leisure-time physical activity. The data from DME suggest that light-to-moderate NEAT constitutes the bulk of activity energy expenditure, and it is this source of total energy expenditure that is being eroded rapidly as communities justifiably strive to improve their developmental status. To monitor the changes in NEAT in DME settings will likely require novel solutions, drawing on the established Physical Activity Epidemiology knowledge base.

The decade after the Second World War, saw the publication of pioneering studies in Physical Activity Epidemiology. Since these early studies, the evidence linking physical activity to health from an EME perspective has burgeoned in quantity and quality such that the evidence is incontrovertible. The prospective and retrospective cohort studies that have provided the bulk of the evidence, consistently reported sizable and significant risk ratios using self-report instruments. This evidence is foundational to the more recent physical activity guidelines which have focussed on public health outcomes as opposed to improvements in physical fitness. While the wealth of data collected using self-report instruments clearly quantified the protective function of physical activity and the risks of physical inactivity, more recent questions have highlighted the need to consider other more objective measures of physical activity. The importance of light-to-moderate intensity physical activity to health and in particular energy balance, strains the accuracy and reliability of self-report measures. Furthermore, quantifying the prevalence of achieving a certain dose of physical activity in a population demands that the measurement be absolute and not relative. The misclassification bias introduced through self-report measures is generally random allowing the relative ordering of physical activity dose into categories (low to high, n -tiles) but with reduced precision. Consequently, the use of objectively-measured PA will improve the precision of point estimates and associated confidence intervals but will not alter the established relationship between physical activity or inactivity and health. In other words, the concurrent collection of self-report and objective measures will likely improve the precision of risk ratios and reduce the confidence intervals, but not fundamentally alter the shape of dose-response relationships. On the basis of population-based surveys that have included concurrent measurement instruments there is growing evidence that self-report

measures are not providing sufficiently accurate estimates of physical activity/inactivity prevalence statistics. Importantly objectively-measured PA will not replace self-report measures, because both instrument types are providing physical activity/inactivity evidence from different vantage points. In other words, subjectively-measured PA provides superior contextual data while objectively-measured PA yields superior quantitative data. It is unlikely then that objectively-measured PA will fundamentally alter physical activity guidelines, but rather provide data which will allow for the fine-tuning of these guidelines, tailoring these guidelines to particular groups within a population.

Work in Physical Activity Epidemiology from a South African perspective has accelerated since the start of the 21st century. Prior to 2000, no national physical activity/inactivity data existed for child or adult populations. There is practically no data using objective measures of physical activity. Specifically within rural African populations any physical activity data is sparse and considering that it is these populations in which NEAT is predominant and declining rapidly, the use of appropriate physical activity measures are urgently required. The current surveillance instruments, specifically in South Africa, are likely not precise enough to probe these changes, and will likely require the consideration of a different approach, analogous to methods used in Nutritional Epidemiology. Finally, from a South African perspective, novel and pioneering methodological and survey studies using objective measures of physical activity in rural African settings should provide the necessary impetus for greater use of multiple physical activity measures in challenging measurement scenarios.

1.7. OBJECTIVES OF THIS THESIS

The use of objective measures of physical activity is playing an increasingly important role in the quantification of free-living physical activity, considering the inherent inaccuracy and insensitivity of self-report physical activity measures. This is especially so in rural settings where light-to-moderate intensity physical activity predominates, and is particularly difficult to measure with some degree of accuracy using current self-report, surveillance instruments. Within the Dikgale Health and

Demographic Surveillance System site, two objective measures have been identified as providing accurate and reliable free-living physical activity data over relatively prolonged periods, under relatively harsh circumstances, with minimum subject burden and cultural acceptability. This data will provide much needed knowledge regarding not only methodological aspects of using objective measures in rural settings, but also provide some initial survey data from a typical rural African setting in South Africa. This thesis therefore attempts to answer a number of research questions that arose when using accelerometers and pedometers in a rural setting.

1.7.1. Accelerometry

1.7.1.1. Chapter 2

- What are the sources and distribution of variance and associated reliability over a number of hours and days the number of hours and days?

1.7.1.2. Chapter 3

- What is the effect of monitor placement and monitor unit on the variance distribution and associated reliability?

1.7.1.3. Chapter 4

- Can a valid Subsistence Activity Index be constructed from subsistence variables?

1.7.1.4. Chapter 5

- What are the implications of accelerometer count distribution and moderate-intensity cut-points in terms of current physical activity guidelines?

1.7.2. Pedometry

1.7.2.1. Chapter 6

- How well does a coiled-sprung research-grade pedometer function in a rural setting?

1.7.2.2. Chapter 7

- How well does a multi-day memory, accelerometer-based pedometer function in a rural setting?

1.7.2.3. Chapter 8

- What are the primary factors (body mass, volume, intensity) contributing to energy expenditure accrued through high ambulation levels in a rural setting?

1.7.2.4. Chapter 9

- Can compliance/non-compliance with physical activity guidelines be inferred using a novel approach to energy expenditure-derived pedometer data?

University of Cape Town

**CHAPTER 2: SOURCES OF VARIANCE AND RELIABILITY OF
OBJECTIVELY MONITORED PHYSICAL ACTIVITY IN RURAL AND
URBAN NORTHERN SOTHO-SPEAKING BLACKS.**

Data in this chapter has been published in the South African Journal of Sports Medicine
20(1): 21-27, 2008.

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2.1. INTRODUCTION

Human movement and the concomitant increase in energy expenditure are fundamental aspects of human existence. The importance of movement-related energy expenditure has been acknowledged since antiquity but has only relatively recently seen substantial research activity.¹⁶¹ Arguably, the dramatic global increase in chronic diseases of lifestyle over the last century has spurred the interest in exploring the importance of human energy expenditure in relation to health¹⁶¹ and has led to evidence-based public health guidelines for health-enhancing physical activity.³³⁰

A number of instruments are available for estimating human energy expenditure and range from paper and pencil methods to doubly-labelled water.^{426,660} Irrespective of the method employed, it is important that the sources and magnitude of the variability of physical activity are quantified so that research activities in physical activity and health are appropriately designed, analysed and interpreted.⁶⁶⁰ By partitioning physical activity variability into discrete components (systematic and random variation), the number of periods of monitoring required to reliably estimate physical activity volumes and patterns of individuals in a population can be determined and deattenuation coefficients calculated to reduce the attenuation of effect statistics.⁶⁶⁰ Importantly, random, biological variation will determine the number of periods of monitoring and consequently aspects of study design such as sample size and statistical power.⁶⁶⁰ It should be noted that assessments of energy intake (diet) and energy expenditure (physical activity) are susceptible to the same types of measurement error.^{391,680}

Numerous studies in industrialised countries have investigated the reliability of objectively monitored free-living physical activity.^{124,176,177,238,293,354,390,440,603,608,619,641} However, few papers have reported sources of variation for either physical activity questionnaires^{390,395} or objectively monitored physical activity.^{354,395} Within the South African context there is a dearth of reliability studies for any form of physical activity assessment.^{78,134,141,322} The reliability of objectively monitored free-living physical

activity in South African samples has not been reported. Moreover, no data have been reported regarding the sources of variation for any type of physical activity measurement instrument in South African samples. From a regional and international perspective, we are not aware of any data from sub-Saharan Africa or any developing country that have addressed variance distribution and reliability of objectively monitored free-living physical activity.

Reliability and variance distribution have been widely investigated within nutritional epidemiology^{456,468,680} but less so in physical activity measures that are often used to estimate physical activity patterns and energy expenditure.⁶⁶⁰ This is probably because of the relatively recent emergence of a new branch of epidemiology, namely physical activity epidemiology.¹⁶¹ Considering the heterogeneity of the South African population, studies investigating the variance distribution and reliability of physical activity assessments across sub-sections of the South African population are required.

The objective of this paper was firstly to investigate the sources and distribution of variance for objectively measured physical activity over a number of hours and days in a sample of rural and urban Northern Sotho-speaking blacks. The second objective was to determine the number of hours and days required to reliably measure 1 hr and 1 day of accelerometer-derived indices of physical activity in this particular South African sample.

2.2. METHODS

2.2.1. Study protocol

The data used in this analysis were collected during the validity trial of the IPAQ which has been reported elsewhere.^{78,141} For this analysis only the accelerometer data were considered. Briefly, black Northern Sotho-speaking rural and urban participants were recruited and contacted twice over an 8-day period. On the first occasion, subjects were recruited, completed a socio-demographic questionnaire and provided anthropometric data. All interviews, anthropometric measures and accelerometer placement were conducted by trained black male and female field

workers. The first author was responsible for securing funding, field worker training, the accelerometer data management and overall data entry, data analysis and data reporting. Anthropometric measures included body mass (kg) and stature (cm) allowing the calculation of BMI. Finally, subjects were instructed on the necessary procedures for wearing the accelerometer. Eight days later the accelerometers were collected. Subjects received a small honorarium on completion of the study. Signed informed consent was obtained from all participants. The study was approved by the Ethics Committee of the University of Limpopo (Turfloop Campus).

2.2.2. Subjects

2.2.2.1. Rural sample

A convenience sample of black employees, resident on farms and villages, were recruited from the plantation section of a local lumber mill situated in the Limpopo Province, South Africa (total $N=31$, males $N=18$, females $N=13$). These workers performed a variety of manual tasks and ensured that plantations were created and maintained, and that raw timber was harvested, sized, cleaned and stacked prior to transport to the saw mill for further processing.

2.2.2.2. Urban sample

A convenience sample was recruited from black academic staff, support staff and students of the University of the Limpopo (Turfloop Campus), and black residents (office workers, teachers) from the surrounding community (Mankweng) and nearby city (Polokwane) (total $N=30$, males $N=14$, females $N=16$). For the most part, these subjects performed tasks typical of office workers, with long periods of sedentary activity (sitting, standing quietly).

2.2.3. Physical activity counts and durations

To objectively quantify free-living physical activity of the subjects, uni-axial accelerometers were worn for at least 8 days. The CSA model 7164 (Computer Science Applications, Inc. Shalimar, FL), now marketed as the MTI Actigraph (MTI Health Services, Fort Walton Beach, FL), is small and unobtrusive (5.1 cm x 4.1 cm x 1.5 cm, 42.6 g).⁶⁶⁰ In this study, the epoch duration was set at 1 min. The accelerometer was worn on the right waist, securely attached to a nylon belt. The

accelerometers could be removed for sleeping and bathing purposes by unclipping the nylon belt. The data were downloaded from the accelerometers onto an IBM-compatible personal computer via an interface unit, for further analysis using CSA-supplied software (DAYBYDAY.XLS, Microsoft Excel©97 macro) and a customised data reduction programme (Microsoft Excel©97 macro). Physical activity counts were defined as total counts (counts.day⁻¹) and average counts (counts.min⁻¹.day⁻¹). Physical activity intensity patterns or durations (min.day⁻¹) of inactivity and moderate and vigorous activity were created according to cut-points defined by Matthews *et al.*³⁹⁰ Inactivity (sitting, standing quietly) was defined as less than 500 counts.min⁻¹. For moderate activity (3-6 METs, 1 MET = 1 metabolic equivalent = 3.5 mlO₂.kg⁻¹.min⁻¹ = 1 kcal.kg⁻¹.hr⁻¹) a distinction was made between activities requiring less ambulation (moderate-1: house work, yard work) and predominantly ambulatory activities (moderate-2: walking). The cut-points for moderate-1 and moderate-2 were defined as 500 - 1 591 counts.min⁻¹ and 1 592 - 5 724 counts.min⁻¹, respectively. Activities, such as running, which record more than 5 724 counts.min⁻¹ were defined as vigorous (>6 METs).

The first and last days of the 8-day monitoring period were excluded. To evaluate the number of hours required to reliably estimate 1 hr of objectively monitored physical activity, the first weekday with at least 14 hr of registration (06h00 to 20h00) was selected. To evaluate the number of days required to reliably estimate one day of objectively monitored physical activity, accelerometer data for 4 days (3 weekdays and 1 weekend day) were used. Only days with at least 10 hr.day⁻¹ (600 min.day⁻¹) of registration were included.¹⁴¹ From the min-by-min data, hourly and daily accelerometry indices were summed (counts.hr⁻¹, counts.day⁻¹, min.hr⁻¹, min.day⁻¹). Accelerometry data of 41 subjects (23 males, 18 females) which constituted 67.2% of the original sample of 61, complied with all the selection criteria.

2.2.4. Statistical analysis

The descriptive analysis comprised residence-specific means and standard deviations and percentages for continuous and categorical variables, respectively.

For skewed continuous accelerometry variables (≥ 2 x standard deviation), residence-specific medians and interquartile ranges were calculated. Differences (rural v. urban) between two independent categorical variables were tested for significance (with continuity correction for small sample sizes).¹⁸ To examine differences (rural v. urban) between two independent continuous variables, an independent t-test was used. Because the distributions of some variables were neither normal nor lognormal a comparable non-parametric test was used (Mann-Whitney U test).

Hourly (14 hr) and daily (4 day) accelerometry indices were rank transformed because the distributions of several residence-specific accelerometer indices were neither normal nor lognormal. To evaluate the sources of variability in ranked accelerometer data, variance components in mixed and random effects models were estimated using restricted maximum likelihood methods.³⁹⁰ Accelerometer indices were the dependant variables for these analyses. Variance components were estimated for subject (inter-individual) variance, trial (hour or day) variance, and residual (intra-individual) variance. The variance components were also expressed as a percentage of the total variance. Inter-individual variance represents true variation between subjects while intra-individual variance represents hour-to-hour or day-to-day variation within subjects. The variance due to the hour or day effect was nested within subjects. To identify variables that could affect the inter-individual variance and thus the reliability we entered age, body mass index, educational level, residence (rural/urban) and sex (male/female) individually as fixed factors. From this preliminary analysis (data not shown) we identified residence and sex as having the most consistent and substantial impact on inter-individual variance. The first analysis was conducted on the whole sample such that variance components for subject, trial (day or hour) and residual were extracted with and without adjustment for fixed effects of residence and sex. From the extracted variance components, intra- to inter-subject variance ratios (σ^2_w / σ^2_B) were calculated, where σ^2_B was the between or inter-individual variance and σ^2_w was the within- or intra-individual variance. To examine possible differences in the distribution of variance (inter-individual, hour or day effect, residual) across residence status, the second analysis was stratified by residence while treating sex as a fixed factor.

Reliability coefficients were calculated from the variance components extracted from the residence-stratified variance component analysis, with sex treated as a fixed factor. Reliability was calculated as an average measure (ICC_M) and a single measure (ICC_S) intraclass correlation coefficient (ICC) using the following equations, $ICC_M = \sigma^2_B / (\sigma^2_B + \sigma^2_w)$ and $ICC_S = \sigma^2_B / (\sigma^2_B + \sigma^2_w / k)$, where σ^2_B was the inter-individual variance, σ^2_w was the intra-individual variance and k was the number of days or hours.⁴⁰⁷ Because unbounded, ranked data were used to obtain an ICC from a model meant for continuous data,¹⁵⁴ the corrected and uncorrected ICC_M from the mean squares of an analysis of variance-based variance component analysis were also calculated.⁴⁰⁷ There was no difference in ICC_M after the correction (data not shown).

Deattenuated 4-day and 14-hr ICC_m were calculated using the formula, $ICC_{true} = ICC_{obs} \times (1 + [\sigma^2_w / \sigma^2_B] / k)^{0.5}$ where ICC_{true} was the true correlation, ICC_{obs} was the observed correlation, σ^2_w was the intra-individual variance, σ^2_B was the inter-individual variance and k the number of monitoring periods.^{391,660} Because random variation (intra-individual variance) reduces the ability to identify significant effects, deattenuation is employed to adjust for random variation such that a better estimate is obtained of the true statistic. To estimate the number of hours and days required to reliably predict 1 hour and 1 day of accelerometry, respectively, the following equation was rearranged to solve for k , $ICC = \sigma^2_B / (\sigma^2_B + \sigma^2_w / k)$ where $ICC = 0.80$. Data was analysed using appropriate statistical software (SPSS for Windows 11.0.1). Significance for all inferential statistics was set at $p < 0.05$.

2.3. RESULTS

Subject characteristics are reported in Table 2.1. Because of the relatively low volume and highly skewed distribution of the recorded vigorous activity (rural: 3.7 ± 6.7 min v. urban: 3.2 ± 5.3 min), the moderate-2 and vigorous variables were combined. Significant differences were found between rural and urban groups for all continuous and categorical variables, except for sex distribution and vehicle ownership. Of note were the significantly lower levels of obesity and inactivity, and greater levels of activity in the rural group compared with the urban group.

Table 2.1. Descriptive characteristics for rural and urban subjects.

	Residence		
	Rural (n = 21)	Urban (n = 20)	<i>P</i> ‡
Continuous variables			
Age (yr)	38.9 (10.4)	32.9 (6.7)	0.037
BMI (kg.m ⁻²)	22.9 (3.9)	27.2 (5.3)	0.006
Accelerometer data (4-day average)			
Activity counts (counts)			
Total counts (counts.day ⁻¹)	644102 (208420)	409341 (169799)	0.001
Average counts (counts.min ⁻¹ .day ⁻¹)	847 (267)	618 (248)	0.008
Duration (min.day ⁻¹)			
Inactivity (0-499 counts)	1078 (92)	1236 (58)	<0.001
Moderate 1 (500-1951 counts)	265 (67)	141 (35)	<0.001
Moderate 2 – Vigorous (>1951 counts) *	94 (55)	51 (65)	0.027
Categorical variables †			
Body mass index classification			
Normal weight (<25 kg.m ⁻²)	76.2 (16)	40.0 (8)	0.042
Overweight to obese (≥25 kg.m ⁻²)	23.8 (5)	60.0 (12)	0.042
Female participants	47.6 (10)	40.0 (8)	0.860
Education (≥Grade 12)	0 (0)	85.0 (17)	<0.001
Ownership of motor vehicle (yes)	14.3 (3)	40.0 (8)	0.132
Electricity available inside house (yes)	19.0 (4)	85.0 (17)	<0.001

data are reported as mean (SD) for all continuous variables except * median (interquartile range) and categorical variables † % (*n*), ‡ *p* values evaluate rural vs. urban differences

Table 2.2. Crude and adjusted intra- to inter-subject variance ratios (σ^2_w / σ^2_B) by monitoring period.

Variables *		σ^2_w / σ^2_B ratio		
		Crude †	Adjusted ‡	% Change §
14-Hours (<i>n</i> = 41)	Total counts	3.44	7.06	105.0
	Average counts	3.80	7.29	91.6
	Inactivity	3.09	9.07	193.2
	Moderate-1	2.75	11.34	312.8
	Moderate-2+vigorous	3.41	5.35	56.9
4-Days (<i>n</i> = 41)	Total counts	0.66	1.01	53.6
	Average counts	0.55	0.73	33.6
	Inactivity	0.58	1.53	163.0
	Moderate-1	0.67	2.49	269.9
	Moderate-2+vigorous	0.77	1.04	35.6

* see Table 1 for variable units, † unadjusted for fixed effects of residence and sex, ‡ adjusted for fixed effects of residence and sex, § % change = [(Adjusted – Crude)/Crude] x 100

Crude and adjusted variability ratios (σ^2_w / σ^2_B) for accelerometer indices are reported in Table 2.2. Both crude and adjusted variability ratios were far higher for hourly accelerometer variables compared with daily accelerometer variables. After adjustment for residence and sex, the variability ratios increased for both 14-hr and 4-day accelerometer variables by 34 - 313%, although the increases were greater for the 14-hr period compared with the 4-day period. Adjustment for residence and sex reduced the inter- or between-subject variability (σ^2_B), thereby increasing the ratio. The higher ratios mean that more periods of objective physical activity monitoring would be required to reliably predict physical activity, especially so for hr-by-hr accelerometer indices.

Total variance in each of the 14-hr accelerometer indices was higher in the urban sample, suggesting that the distribution of activity and inactivity levels in the urban sample was more heterogeneous compared with the rural sample (Table 2.3).

Table 2.3. Variance component analysis of the 14-hour accelerometer output in rural and urban subjects.

Sources of variance [†]	Activity counts [*]				Activity duration [*]					
	Total counts		Average counts		Inactivity		Moderate-1		Moderate-2+vigorous	
	Variance	%	Variance	%	Variance	%	Variance	%	Variance	%
<i>Rural (n = 21)</i>										
Inter-individual	1669	8.1	1672	8.1	1022	4.5	670	3.0	3317	14.4
Hour of day	3483	16.9	3376	16.3	4052	17.7	3635	16.5	3360	14.6
Intra-individual	15471	75.0	15656	75.6	17762	77.8	17726	80.5	16298	70.9
Total	20623	100	20703	100	22836	100	22031	100	22974	100
<i>Urban (n = 20)</i>										
Inter-individual	4912	16.9	4802	16.1	3998	16.6	3233	14.4	4745	17.8
Hour of day	1712	5.9	594	2.0	1565	6.5	1390	6.2	1311	4.9
Intra-individual	22477	77.2	24414	81.9	18539	76.9	17904	79.5	20622	77.3
Total	29101	100	29810	100	24101	100	22527	100	26678	100

^{*} see Table 1 for units, [†] adjusted for fixed effects of sex, % sources of variance as a percentage of total variance

For both groups intra-individual variability was the largest source of variance (71 - 82%). The distribution of inter-individual and hour of day variability differed between the rural and urban group. In the rural group, hour of day variability was the second highest source of variance (15 - 18%), followed by inter-individual variability (3 - 14%). In contrast, for the urban group, inter-individual variability was the second highest source of variance (14 - 18%), followed by hour of day variability (2 - 7%).

Unlike the 14-hr accelerometer variability, total variance for the 4-day period was not consistently higher in the rural or urban group (Table 2.4). In the rural group, inter-individual variance (47 - 58%) tended to be slightly higher than intra-individual variance (43 - 51%), while day of week variability was lowest (0 - 6.5%) of all sources of variance. For accelerometer counts and moderate-2+vigorous activity level, variance distribution in the urban group mirrored that of the rural group; 49 - 57% inter-individual, 44 - 51% intra-individual and 0 - 2% day of week. In contrast, the urban group intra-individual variance for inactivity and moderate-1 levels were high compared with inter-individual variance: 69 - 91% v. 8 - 31%, respectively.

Table 2.4. Variance component analysis of the 4-day accelerometer output in rural and urban subjects.

Sources of variance [†]	Activity counts [*]				Activity duration [*]					
	Total counts		Average counts		Inactivity		Moderate-1		Moderate-2+vigorous	
	Variance	%	Variance	%	Variance	%	Variance	%	Variance	%
<i>Rural (n = 21)</i>										
Inter-individual	864	50.1	967	57.5	756	47.3	680	44.7	929	48.9
Day of week	11	0.6	0	0.0	61	3.8	99	6.5	0	0.0
Intra-individual	848	49.2	713	42.5	780	48.8	743	48.8	970	51.1
Total	1722	100	1680	100	1597	100	1521	100	1899	100
<i>Urban (n = 20)</i>										
Inter-individual	906	48.6	1183	56.5	375	30.8	91	8.4	975	49.0
Day of week	0	0.0	0	0.0	0	0.0	3	0.3	45	2.3
Intra-individual	959	51.4	910	43.5	842	69.2	999	91.3	970	48.7
Total	1865	100	2093	100	1217	100	1093	100	1990	100

^{*} see Table 1 for units, [†] adjusted for fixed effects of sex, % sources of variance as a percentage of total variance

Attenuated reliability coefficients for 14-hr accelerometer indices were less than 0.8 and were lower in the rural group compared with the urban group (Table 2.5).

Table 2.5. Intraclass correlation reliability analysis of 14-hour accelerometer output indices in rural and urban subjects.

Variables [*]		Reliability (ICC)		Required number of hours to achieve a reliability of 0.8
		14 hours [†]	1 hour	
<i>Rural (n = 21)</i>				
Total counts		0.55 (0.74)	0.08	45.4
Average counts		0.55 (0.74)	0.08	45.5
Inactivity		0.40 (0.63)	0.04	85.4
Moderate-1		0.31 (0.55) [‡]	0.03	127.6
Moderate-2+vigorous		0.70 (0.84)	0.14	23.7
<i>Urban (n = 20)</i>				
Total counts		0.74 (0.86)	0.17	19.7
Average counts		0.73 (0.85)	0.16	20.8
Inactivity		0.74 (0.86)	0.17	20.1
Moderate-1		0.70 (0.84)	0.14	23.9
Moderate-2+vigorous		0.75 (0.87)	0.18	18.5

^{*} see Table 1 for variable units, ICC = intraclass correlation coefficient, [†] deattenuated ICC_m appear in parenthesis, all ICC significant ($p < 0.05$) except [‡] ($p = 0.1036$)

Hourly moderate-2+vigorous activity was the most reliable for both the rural and urban groups. The most unreliable accelerometer indices were the inactivity and moderate-1 levels in the rural group. Excluding the two lowest reliabilities, the attenuated reliability coefficients increased by 0.12 to 0.19 units after accounting for intra-individual variation, while the reliability coefficients for the inactivity and moderate-1 indices increased by ~0.23 units after deattenuation. The difference between rural and urban reliability remained even after deattenuation of all the reliability coefficients. To achieve a reliability coefficient of 0.8 for hourly accelerometer variables in the urban group would require approximately 2 periods of 12-hr monitoring (24 hr). In contrast, approximately 4 - 11 periods of 12-hr monitoring

(48 - 130 hr) would be required in the rural group. In both groups, moderate-2+vigorous activity required fewer hours of monitoring to reliably predict 1 hr of activity (19 - 24 hr) compared with other accelerometer indices.

Table 2.6. Intraclass correlation reliability analysis of 4-day accelerometer output indices in rural and urban subjects.

Variables *		Reliability (ICC)		Required number of days to achieve a reliability of 0.8
		4 days †	1 day	
<i>Rural (n = 21)</i>	Total counts	0.80 (0.89)	0.50	4.0
	Average counts	0.84 (0.92)	0.58	3.0
	Inactivity	0.78 (0.88)	0.47	4.5
	Moderate-1	0.76 (0.87)	0.45	5.0
	Moderate-2+vigorous	0.79 (0.89)	0.49	4.2
<i>Urban (n = 20)</i>	Total counts	0.79 (0.89)	0.49	4.2
	Average counts	0.84 (0.92)	0.57	3.1
	Inactivity	0.64 (0.80)	0.31	9.0
	Moderate-1	0.27 (0.75) ‡	0.08	43.8
	Moderate-2+vigorous	0.79 (0.89)	0.49	4.2

* see Table 1 for variable units, ICC = intraclass correlation coefficient, † deattenuated ICC_m appear in parenthesis, all ICC significant ($p < 0.05$) except ‡ ($p = 0.1799$)

The reliability of 4-day accelerometer indices was generally higher compared with the 14-hr accelerometer variables (Table 2.6). Attenuated reliability coefficients in both the rural and urban groups were nearly identical except for the low reliability coefficients for inactivity and moderate-1 indices in the urban group. The values of 8 of the 10 attenuated reliability coefficients increased by 0.08 - 0.10 units after accounting for the intra-individual variation. The effect of deattenuation was not greater in the rural group (mean difference = 0.10 units) or the urban group (mean difference = 0.09 units) for 8 of the 10 reliability coefficients. Because of the higher intra-individual variation in the inactivity and moderate-1 activity indices of the urban group, the attenuated reliability coefficients increased by 0.16 to 0.48 units. In the rural group, at least 5 days of monitoring would be required to reliably predict one day of activity or inactivity. However, in the urban group, to reliably predict one day of inactivity, moderate-1 activity and moderate-2+vigorous activity would require 9, 44 and 4 days of monitoring, respectively.

2.4. DISCUSSION

This study is novel for two reasons. It is the first analysis that has reported on the reliability of objectively monitored physical activity in a South African setting. It is also the first analysis that has investigated the distribution of variance for any physical activity measure in a South African sample. The principal findings of this analysis

were firstly that the distribution of variance differed depending on the sampling period. For the 4-day sampling period, between- or inter-subject variability, which represents true differences in physical activity indices between subjects, was at least as large as within- or intra-individual variability (behavioural variability), while day of week accounted for little of the variance (<7%). In contrast, for the 14-hr monitoring period, intra-individual variation accounted for more than 70% of the variance, while hour of day and inter-individual variation accounted for the remaining variance. Secondly, irrespective of the monitoring period (14-hr or 4-day), total counts, average counts and moderate-2+vigorous activity tended to be the most reliable measures requiring the fewest number of monitoring periods. Thirdly, adjustment for basic demographic factors such as residence and sex prevents the under-estimation of monitoring days required so that reliable estimates of physical activity volumes and patterns can be obtained.

The authors are not aware of any other analysis investigating the reliability and variance distribution of accelerometry data collected in adult populations over monitoring periods shorter than a day. The results from the 14-hr monitoring period of the present study show that a reversal in variance distribution occurs in comparison to the 4-day period; intra-individual variance > inter-individual variance. Moreover, the relative contributions of the inter-individual variance and hour of day variance to the total variance were contrasted in the two residence-defined groups. This can be explained by the fact that the physical activity patterns in the rural group show relatively large changes over the course of the 14 hr, ranging from physical inactivity in the morning to being physically active during the working day, which is interspersed with breaks (tea, lunch), and back again to physically inactive levels during the late afternoon and evenings. This type of hourly activity pattern was quite homogenous throughout the rural group such that inter-individual variance was lower. In contrast, the activity patterns of the urban group tended to remain relatively constant over the period of the 14 hr, although this could differ between individuals, which explain the higher inter-individual variance in this group. It is likely then that similar investigations of hourly physical activity patterns in different samples will yield variance distributions that are in accord with the particular activity demands required of those samples. Importantly, the number of periods required to reliably estimate

physical activity volumes and patterns will differ from sample to sample, particularly over shorter monitoring periods where variance contrasts between groups can be large. The greater intra-individual variance in the 14-hour monitoring period, although in accord with the variance distribution in questionnaire-based physical activity assessment cannot be because of factors related to the imprecision of measurement found in non-objective physical activity assessment.³⁹⁴ Rather, the greater intra-individual variance could be due to the natural variation in physical activity behaviour from hour to hour.

The results for the 4-day monitoring period are generally in agreement with data from North America in that inter-individual variation accounted for most of the variation.¹⁵ Matthews *et al.* examined accelerometry data collected from 92 adults over a period of 21 consecutive days.³⁹⁰ They found inter-individual variation contributed the most to overall variance (55 - 60%) followed by intra-individual variance (30 - 45%) and day of the week variance (1 - 8%). The number of days required to achieve 80% reliability for estimating activity counts and moderate-2+vigorous activity was 3 - 4 days,³⁹⁰ which is in agreement with the present results of 4 - 5 days. Moreover, the North American data also found that estimating physical inactivity was more unreliable requiring more days of monitoring compared to most of the physical activity indices (7 days) and is in agreement with our finding of 5 - 10 days in the present results. The difference between inter-individual and intra-individual variance in the present study was not as pronounced as found by Matthews *et al.*³⁹⁰ but is still quite different to the variance distribution found in questionnaire-based physical activity assessment (50 - 60% intra-individual, 20 - 30% inter-individual).³⁹⁵ It has been suggested that the differences in variance distribution between objective and self-reported physical activity assessment may be due to factors such as precision of objective measuring instruments, the ability of objective measuring instruments to detect common, light intensity activities and the level of variability present in self-report instruments.³⁹⁰

The results of the present investigation are also accord with the prediction of Matthews *et al.* that because of the differences between study samples in terms of variance distribution, each study sample would have different sampling

requirements.³⁹⁰ The present results have shown general agreement in that inter-individual variance is at least as great as intra-individual variance. Specific differences have also been shown in the present study, in that the differences between inter-individual and intra-individual variances are not as pronounced as those found by others.³⁹⁰ Consequently, the number of days required to reliably estimate the various physical activity and inactivity indices differ from that proposed by others.³⁹⁰ The predicted qualitative differences between our results from those of others³⁹⁰ would appear to add further support the validity of the present analysis.

It would certainly be profitable to analyse the larger South African accelerometry dataset that was part of the IPAQ validation study, especially because of the heterogeneity of the South African population. This dataset contains accelerometry data from a relatively large sample of subjects ($N > 100$) differing in age, body composition, education level, ethnicity, fitness, language, residence, sex, and socio-economic status. The examination of the reliability and the variance distribution of this dataset would provide valuable information for the South African researcher. There is a lack of published information regarding the number of days of objectively monitored physical activity that would be required to reliably estimate objectively measured physical activity levels and patterns in specific sub-sections of the South African population.

The strength of the present study is firstly the uniqueness of the analysis within a South African context, which will hopefully provide further motivation and impetus for more analyses of this kind. Secondly, this analysis provides reliability and variance estimates for a South African sample of a particular ethnicity, language and residence status. The weakness of this study is the relatively low number of subjects. However, the fact that our results concur generally and differ specifically, as expected, with the results of a similar, larger analysis,³⁹⁰ suggests that despite the relatively small sample size the results of the present analysis are valid. It should also be noted that some of the stratified random effects analyses performed by Matthews *et al.* were done on sample sizes as low as 14.³⁹⁰

In conclusion, this analysis has provided quantitative estimates of the reliability and distribution of variance of objectively measured physical activity measures in a specific ethnic and language group, over two monitoring periods (14-hr and 4-day). Further analyses using larger sample sizes and in different sub-sections of the South African population are required for both questionnaire-based and objectively measured physical activity indices.

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CHAPTER 3: MONITOR PLACEMENT, SOURCES OF VARIANCE AND RELIABILITY OF FREE-LIVING PHYSICAL ACTIVITY – A PILOT INVESTIGATION

Data in this chapter has been published in the South African Journal of Sports Medicine 21(1): 16-21, 2009.

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3.1. INTRODUCTION

The use of accelerometers by researchers to objectively monitor physical activity has seen a dramatic increase since 1997.⁶⁰⁴ With the greater use of uni-axial accelerometers in large field studies,⁶⁰⁵ important questions arise relating to possible sources of measurement error, such as monitor placement.^{607,662} To date a number of laboratory-based studies have considered the effects of different placement positions on the output of uni-axial accelerometers^{663,689} and the intra- and inter-instrument variability of uni-axial accelerometers using mechanical settings^{93,414,448} or motorised treadmill trials.^{95,448,531,609,666} Few studies have employed free-living protocols when evaluating the effect of placement position of movement monitors or the inter-instrument reliability of movement monitors.^{404,449,689}

Only one free-living study has considered the placement position or inter-instrument reliability of uni-axial accelerometers by having subjects wear two monitors on either side of the hip.⁴⁰⁴ That study was carried out in a highly urbanised setting, during the waking hours of one highly structured day, using students and staff from a university setting who were recreational runners and accumulated significant amounts of vigorous physical activity.⁴⁰⁴ Moreover, in their statistical analyses, McClain *et al.*⁴⁰⁴ did not report the possible effect of monitor placement on variance distribution³⁹⁰ nor did they examine agreement⁷² between the two placement positions. Consequently, similar and more expanded analyses of free-living samples with more variable day-to-day physical activity patterns are required. Importantly, rural subjects with low, recreational (vigorous) physical activity but high work-related (moderate) physical activity demands should be recruited.

Uni-axial accelerometers demonstrate low intra-unit variability but do exhibit inter-unit variability such that post-measurement adjustment in multivariate analysis has been used to account for this variance which could otherwise dilute the true relationship between a health outcome and accelerometer output.⁹⁴ In this regard, Welk *et al.* showed that 0.9% of the variance for the raw counts obtained during multi-speed treadmill trials could be attributed to individual uni-axial accelerometer

units.⁶⁶³ There is thus a need to determine if this variance due to inter-unit variability is present or possibly even greater in free-living conditions than has been observed in laboratory trials.

The objectives of this pilot investigation were firstly to evaluate the effect of monitor placement and monitor units on the variance distribution in relation to other sources of variance, and secondly to determine if monitor position had practically significant effects on reliability statistics, specifically in an adult population exhibiting low levels of vigorous, recreational physical activity but high levels of moderate work-related physical activity.

3.2. METHODS

3.2.1. Study protocol

The accelerometry data used in this analysis was collected during the validity trial of the IPAQ.^{78,134,141} Briefly, participants were recruited to wear two uni-axial accelerometers and contacted twice over an 8-day period. On the first occasion, subjects were recruited, provided anthropometric data and were instructed on the necessary procedures for wearing the accelerometers, one on either side of the hip (RH = right-hand side hip, LH = left-hand side hip). Eight days later the accelerometers were collected. All interviews, anthropometric measures and accelerometer placement were conducted by trained black male and female field workers. The first author was responsible for securing funding, field worker training, the accelerometer data management and overall data entry, data analysis and data reporting. Subjects received a small honorarium on completion of the study. Signed informed consent was obtained from all participants. The study was approved by the Ethics Committee of the University of Limpopo (Turfloop Campus).

3.2.2. Subjects

A convenience sample of seven black adult males ($n = 4$, 30.0 ± 0.8 yrs, 175.7 ± 3.2 cm, 63.8 ± 5.9 kg) and females ($n = 3$, 38.7 ± 7.0 yrs, 155.5 ± 4.8 cm, 56.4 ± 4.5 kg), resident on farms and villages, were recruited from the plantation section of a local

lumber mill situated in rural Limpopo Province, South Africa. All participants recruited were BMI $<27 \text{ kg.m}^{-2}$. These forestry workers performed a variety of manual tasks and ensured that plantations were created and maintained, and that raw timber was harvested, sized, cleaned and stacked prior to transport to the saw mill for further processing.

3.2.3. Physical activity counts and durations

To objectively quantify free-living physical activity of the subjects, two uni-axial accelerometers were worn for at least eight days. The CSA model 7164 (Computer Science Applications, Inc. Shalimar, FL), now marketed as the MTI Actigraph (MTI Health Services, Fort Walton Beach, FL), is small and unobtrusive (5.1 cm x 4.1 cm x 1.5 cm, 42.6 g).⁶⁶¹ The accelerometers were worn on the RH and LH, securely attached to a nylon belt. The accelerometers could be removed for sleeping and bathing purposes by unclipping the nylon belt. Subjects were carefully instructed as to the proper positioning of the accelerometers (mid-axillary line). The min-by-min data was downloaded from the accelerometers onto an IBM-compatible personal computer via an interface unit, for further analysis using proprietary software (DAYBYDAY.XLS, Microsoft® Excel 97 macro) and a customized data reduction programme (Microsoft® Excel 2002 macro). Physical activity counts were defined as total counts (counts.day⁻¹) and average counts (counts.day⁻¹.min⁻¹ = total counts / registered time for counts.min⁻¹ ≥ 1). Physical activity volumes (min.day⁻¹) of inactivity and moderate and vigorous activity were derived using previously defined cut-points.^{390,404} Inactivity (lying, sitting, standing quietly, light activity) was classified as 0-499 counts.min⁻¹. For moderate activity (3-6 METs, 1 MET = 1 Metabolic Equivalent = $3.5 \text{ mlO}_2.\text{kg}^{-1}.\text{min}^{-1} = 1 \text{ kcal.kg}^{-1}.\text{hr}^{-1}$) a distinction was made between activities requiring less ambulation (moderate-1: house work, yard work) and predominantly ambulatory activities (moderate-2: walking). The cut-points for moderate-1 and moderate-2 were defined as 500-1591 counts.min⁻¹ and 1592-5724 counts.min⁻¹, respectively. Activities, such as running, which record ≥ 5725 counts.min⁻¹ were defined as vigorous (>6 METs). The amount of activity accumulated in bouts of ≥ 10 min (bouts separated by at least 1 min) for the moderate-1 and moderate-2+vigorous categories were also derived. The first and last days of the eight-day monitoring period were excluded. Only weekdays with at

least 8 hr.day⁻¹ (480 min.day⁻¹) of registration (counts.min⁻¹ ≥1) were considered. This would represent the minimum of a 40-hour, 5-day working week in this sample. Valid accelerometer data for the first three weekdays were used for all subsequent analyses. A three-weekday period was selected because three subjects provided a minimum of three weekdays of valid accelerometer data.

3.2.4. Statistical analysis

Descriptive statistics comprised means and standard deviations. If data distribution was non-normal, the parametric results were confirmed with transformed (natural logarithms) or ranked data. Data were analysed using appropriate statistical software (SPSS for Windows 13.0). Confidence intervals (95%CI) were calculated as required. Significance for all inferential statistics was set at $p < 0.05$.

To evaluate the sources of variability in accelerometer data, variance components in mixed effects models were estimated using restricted maximum likelihood methods.³⁹⁰ Accelerometer raw output and derived indices were the dependant variables for these analyses. Variance components were estimated for subject (inter-individual) variance, monitor unit variance (eight units), trial variance (three trials), monitor position variance (two positions), and residual (intra-individual) variance. The variance components were expressed as a percentage of the total variance. Inter-individual variance represents true variation between subjects while intra-individual variance represents day-to-day variation within subjects. The variance due to monitor unit, trial and monitor position effects were nested within subjects. Gender and day of the week were entered as fixed factors. Using the same set of fixed and random factors, a separate analysis was performed on the raw accelerometer data (counts.day⁻¹) to test for possible interaction of subjects by monitors.⁶⁶⁶

A multivariate, two-way repeated-measures analysis of variance was used to examine possible differences across trials for RH and LH accelerometer variables. Separate analyses were conducted with sex entered as a between-subjects factor, and interactions between sex and hip placement or trial. In order to compare the accelerometer output between RH and LH, the mean difference and limits of agreement for repeated measurements were calculated for all accelerometer

variables.⁷² We did not use the RH and LH within-subject variances across trials to adjust the variance of differences. Within-subject variances for any accelerometer variable did not differ significantly between RH and LH ($p > 0.4$) such that any adjustment using within-subject variance would simply inflate the variance of differences. This inflation would simply mean that within-subject variance across trials was greater than the RH-LH difference variance. Bland-Altman plots and Q-Q normal probability plots of difference scores were constructed to visually assess the limits of agreement and distribution of difference scores, respectively.⁷² For comparative purposes,⁴⁰⁴ we also calculated a coefficient of variation from the standard deviation of the differences of the transformed raw data (natural logarithms) using the following formula (coefficient of variation = $100 \times [e^{SD} - 1]$).²⁷⁶ Because the moderate-2+vigorous (bouts ≥ 10 min) contained zero values, we added one to all raw values before taking the natural logarithms of the raw values. Effect sizes (d) were calculated from the mean difference and the standard deviation of the differences obtained during the limits of agreement analysis (raw values), and interpreted according to Cohen's conventions; 0.20 (small), 0.50 (moderate), 0.80 (large).¹²² The ICC_m (intraclass correlation coefficient; average measure, absolute agreement, two-way random effects)⁴⁰⁷ was calculated (RH vs. LH) for each trial. Thereafter, the mean ICC_m was calculated from the ICC_m of three trials.

Subjects were also classified according to the ACSM/CDC guidelines (≥ 30 min.day⁻¹ of moderate-2+vigorous activity accumulated in bouts ≥ 10 min)⁴⁷³ for each trial and monitor position. Agreement between RH and LH for each trial (7 pairs of data) and for all trials combined (21 pairs of data) was assessed by constructing 2-by-2 tables and calculating Cohen's kappa (κ) statistic.

3.3. RESULTS

Six of the eight units were used twice; once on the RH and once on the LH. Registered time for counts ≥ 1 ranged from 8.12 hr to 14.45 hr (10.18 ± 1.75 hr) and did not differ significantly between RH and LH monitors (RH: 10.18 ± 1.91 hr; LH: 10.18 ± 1.63 hr; mean difference = -0.01 hr, $p=0.9771$). There was no significant difference across trials for registered time for RH or LH monitors ($p>0.2$).

Descriptive statistics for RH and LH accelerometer raw output and derived variables are reported in Table 3.1. Because the volume of vigorous activity accumulated was low (RH: 6 ± 12 min.day⁻¹, LH: 6 ± 11 min.day⁻¹) and distribution was skewed, a separate variable was constructed which combined moderate-2 and vigorous activity. Repeated-measures analyses found no significant differences across the three trials for any accelerometer variable ($p > 0.1$) nor any significant differences between hip placement or sex for any accelerometer variable ($p > 0.4$), except for moderate-1 (bouts ≥ 10 min) where females accumulated significantly more activity than males (34 min, $p = 0.0081$) (Table I). There was no interaction between sex and trial or hip placement ($p > 0.2$). There was no marked difference in significance using the raw data or rank transformed data for the moderate-2+vigorous (bouts ≥ 10 min) variable, consequently the p -values from the raw data are reported.

Effect sizes for the mean differences between RH and LH ranged from $d = 0.02$ to $d = 0.15$ (small effect) for all accelerometer variables. The 95% limits of agreement in Table I represent the area within which 95% of the mean differences would be expected to fall, if the differences are normally distributed.⁷² The difference scores (RH minus LH) were randomly distributed irrespective of the magnitude of the accelerometer variables and the difference scores were normally distributed (data not shown). Agreement analysis revealed no systematic bias in mean differences for any accelerometer variables. Limits of agreement were similar for moderate-1 and moderate-2+vigorous variables (Table 3.1).

Table 3.1. Descriptive statistics for accelerometer raw output and derived indices.

Raw output and derived indices	Monitor positions			Agreement ^{††}
	Right-hand side hip ^{**}	Left-hand side hip ^{**}	Significance ^{††}	
Total counts [*]	761 635 (212 074)	763 290 (178 772)	0.2755	-1 655 (-151 016 to 147 706)
Average count [†]	999 (215)	1 008 (177)	0.2376	-9 (-140 to 122)
Inactivity ^{‡§}	1 026 (102)	1 024 (91)	0.6197	+2 (-50 to 54)
Moderate-1 [‡]				
(bouts ≥ 1 min)	284 (62)	285 (59)	0.1305	-1 (-33 to 30)
(bouts ≥ 10 min)	44 (23)	46 (19)	0.1854	-2 (-24 to 20)
Moderate-2 + vigorous [‡]				
(bouts ≥ 1 min)	130 (50)	131 (40)	0.1529	0 (-36 to 35)
(bouts ≥ 10 min)	19 (22)	20 (18)	0.9841	-1 (-20 to 19)

^{*} total counts = counts.day⁻¹; [†] average counts = counts.day⁻¹.min⁻¹; [‡] activity duration = min.day⁻¹; [§] 0-499 counts.min⁻¹; ^{||} 500-1 951 counts.min⁻¹; ^{††} ≥ 1 952 counts.min⁻¹; ^{**} estimated marginal mean (SD) of three trials; ^{††} trial main effect p -value; ^{††} mean difference (95% limits of agreement), main effect significance for hip differences $p > 0.7$.

The distribution of variance is reported in Table II. Monitor position did not contribute to the variability of any of the accelerometer variables. The variability due to

individual monitor units was 0.3% to 1.7% for raw and derived accelerometer data. There was no interaction for subjects-by-monitors. Inter-individual variance was greater than intra-individual variance for all accelerometer variables, except the moderate-1 (bouts ≥ 10 min) variable.

Of all the variance components nested within-subjects, trial contributed the most. There was no marked difference in variance components using the raw data or rank transformed data for the moderate-2+vigorous (bouts ≥ 10 min) variable, consequently the variance from the raw data is reported in Table 3.2. The variance components reported in Table 3.2 for the moderate-1 (bouts ≥ 10 min) variable was obtained from natural logarithm transformation.

Table 3.2. Variance component analysis of 3-day accelerometry raw output and derived variables.

Sources of variance [†]	Activity counts [*]		Activity duration [*]				
	Total	Average	Inactivity	Moderate-1		Moderate-2 + Vigorous	
				Bouts ≥ 1 min	Bouts ≥ 10 min	Bouts ≥ 1 min	Bouts ≥ 10 min
Inter-individual	79.0	67.1	68.4	60.7	23.5	68.8	53.8
Intra-individual	21.0	32.9	31.6	39.3	76.5	31.2	46.2
Position [‡]	0.0	0.0	0.0	0	0.0	0.0	0.0
Trial [§]	3.1	7.3	23.7	29.1	10.1	8.2	0.0
Monitor	1.7	0.0	0.7	0	0.3	0.0	0.0
Residual	16.2	25.6	7.2	10.2	66.1	23.0	46.2
Total	100	100	100	100	100	100	100

Data reported as a percentage of total variance; ^{*} see Table 1 for units and cut-point definitions; [†] adjusted for gender and day of the week; [‡] position (right-hand side, left-hand side); [§] trial (1, 2, 3); ^{||} monitor (8 units).

The reliability analysis is reported in Table 3.3. The coefficient of variation ranged from 2.7% to 10.5% for raw and derived variables, except for moderate-1 and moderate-2+vigorous variables (16.0% to 72.8%). ICC_m for four of the six accelerometer variables were >0.90 . The ICC_m for trial 1 and trial 3 of the moderate-1 (bouts ≥ 10 min) variables were low and insignificant, resulting in a low mean ICC_m. Transforming the moderate-1 (bouts ≥ 10 min) data did not improve the results. The high intra- to inter-subject variance ratio for the moderate-1 (bouts ≥ 10 min) data (Table 3.2) would account for the continuing low ICC_m. In contrast, the low ICC_m for the moderate-2+vigorous (bouts ≥ 10 min) reported in Table 3.3 was the result of averaging an insignificant ICC_m for trial 1 and significant ICC_m for trials 2-3. Rank transforming the moderate-2+vigorous (bouts ≥ 10 min) data resulted in significant reliability coefficients (consistency, two-way random effects) for all trials ($p \leq 0.01$) resulting in a mean ICC_m = 0.92.⁴⁰⁷

Table 3.3. Reliability analysis of 3-day accelerometry raw output and derived indices.

Raw output and derived indices *	Coefficient of variation †	Intraclass correlation coefficient‡			
		Trial 1	Trial 2	Trial 3	Mean §
Total counts	10.5	0.95	0.97	0.96	0.96
Average counts	6.3	0.98	0.92	0.96	0.95
Inactivity	2.7	0.93	0.98	0.94	0.95
Moderate-1					
(bouts ≥1 min)	5.7	0.86	0.99	0.98	0.94
(bouts ≥10 min)	33.8	0.72 §	0.78	0.39 §	0.63
Moderate-2 + vigorous					
(bouts ≥1 min)	16.0	0.96	0.89	0.96	0.94
(bouts ≥10 min)	72.8	0.61 §	0.92	0.95	0.83

* see Table 1 for units and cut-point definitions; † percentage; ‡ average measure intraclass correlation coefficient for RH v. LH; all trial ICC significant ($p < 0.02$) except § $p = 0.08$; § arithmetic mean for trial 1-3.

Only two subjects were misclassified in terms of achievement of ACSM/CDC guidelines between RH and LH monitors; one subject on trial 1 and one subject on trial 3. There were no misclassifications for trial 2. Agreement between hip positions was significant for trial 2 ($\kappa = 1.00$, $p = 0.0082$) but not trials 1 and 3 ($\kappa = 0.70$, $p = 0.05334$). Overall (trial 1-3) agreement was significant ($\kappa = 0.79$, $p = 0.0002$).

3.4. DISCUSSION

This study is the first analysis, albeit preliminary in nature, which has reported on the effect of monitor placement on the variance distribution and reliability of uni-axial accelerometer output and derived variables obtained during free-living conditions in a South African setting. The principal findings of this analysis were firstly that there were no statistically significant differences between hip positions for raw or derived accelerometer variables. Secondly, greater variability was apparent for the moderate-2+vigorous variables, especially so for time accumulated in bouts ≥ 10 min for both moderate categories. Thirdly, individual accelerometer units accounted for nearly two percent of the variance for raw accelerometer counts.

Welk *et al.* were the first to demonstrate that at a moderate treadmill walking speed of $4.8 \text{ km} \cdot \text{hr}^{-1}$, different uni-axial accelerometer hip positions (anterior axillary, mid-axillary, posterior axillary) had a significant effect ($p < 0.05$) on accelerometer output ($\text{counts} \cdot \text{min}^{-1}$) such that variability (percentage of mean score) was 30% compared to 3% for two other accelerometers (Biotrainer and Tritrac).⁶⁶³ These findings suggest that variability is more likely to increase at moderate intensities during free-living trials where monitor position is not accurately controlled.

Our results are in agreement with laboratory treadmill studies that have found greater variability between uni-axial accelerometers mounted across hips (RH vs. LH) at moderate intensities compared with vigorous intensities.^{95,448} Nichols *et al.* found lower reliability across hip placement for slow speeds (ICC = 0.55, 3.2 km.hr⁻¹) compared with faster speeds (ICC = 0.91, 6.4 km.hr⁻¹).⁴⁴⁸ Similarly, Brage *et al.* demonstrated lower agreement at moderate walking speeds (4-6 km.hr⁻¹) compared with faster running speeds (8-14 km.hr⁻¹), even though ICC > 0.91.⁹⁵ Importantly, these differences remained even after calibration of the individual monitors.

The effect of hip vs. lower back positions on uni-accelerometer output has been investigated during laboratory treadmill⁶⁸⁹ and free-living trials.^{449,689} Yngve *et al.* reported significant differences ($p < 0.01$) between hip and lower back positions for normal and fast walking and jogging (4.3, 5.8 and 9.6 km.hr⁻¹, respectively) irrespective of setting (indoor athletics track or treadmill).⁶⁸⁹ The absolute percentage error ($[(\text{Hip} - \text{Back}) / \text{Back}] \times 100$) was greatest for the normal to fast walking (9.5% and 7.2%, respectively) which occurred in the moderate (1952-5724 counts.min⁻¹) range, and lowest for jogging (4.5%; ≥ 5725 counts.min⁻¹ range). It was suggested that the differential findings between walking and jogging were due to changes in vertical displacement of the hip compared with the lower back during the transition from fast walking to jogging.⁶⁸⁹ During a 7 day free-living trial, no significant difference was found between monitor positions (-10 counts.min⁻¹, $p = 0.23$, 95% limits of agreement: -102 to 82 counts.min⁻¹). Moreover, the amount of daily moderate-to-vigorous time predicted from four METs vs. counts.min⁻¹ equations did not differ between monitor positions.⁶⁸⁹ During a four day free-living trial in children, Nilsson *et al.* demonstrated no difference between hip and lower back positions for raw counts (22 counts.min⁻¹, $p = 0.20$, 95% limits of agreement: -110 to 154 counts.min⁻¹).⁴⁴⁹ The wide limits of agreement was due to two subjects and might have been caused by specific movements that result in differences in movements between the hip and lower back. A significant difference ($p < 0.01$) between output for hip and lower back positions was found only when data was sampled over short periods (5 sec epochs) and only in the moderate range (1952-5725 counts.min⁻¹). Short sampling periods might be more likely to capture even small differences in movement at different body sites.⁴⁴⁹

More recently, McClain *et al.* have been the first to show that in free-living conditions, RH-LH comparisons exhibit greater variability for the moderate-2 range (500-1951 counts.min⁻¹),⁴⁰⁴ thus confirming the laboratory treadmill findings of greater variability at walking speed intensities.^{95,448} Our results are in accord with the lower variability reported by McClain *et al.* for total counts, inactivity and moderate-1 variables.⁴⁰⁴ However, in contrast to McClain *et al.*, we have found higher variability for the moderate-2+vigorous physical activity (MVPA) categories (≥ 1952 counts.min⁻¹; bouts ≥ 1 min and ≥ 10 min).⁴⁰⁴ These apparently contradictory findings are due to the selective subject recruitment strategies employed in this study and by McClain *et al.*.⁴⁰⁴

McClain *et al.* purposively selected highly active individuals (runners) which resulted in approximately 65% of MVPA time being accumulated from vigorous activity (≥ 5725 counts.min⁻¹).⁴⁰⁴ Consequently, the increased variability of the moderate-2 range was diluted by the larger contribution of the vigorous range. The present study, on the recommendation of McClain *et al.*,⁴⁰⁴ selected subjects who were not vigorously active but rather accumulated activity in the moderate-1 and moderate-2 activity zones. This is evident by a three-fold greater moderate-1 time, a nearly 5-fold greater moderate-2 time and an eight-fold lower vigorous time, compared with McClain *et al.*.⁴⁰⁴ Moreover, the moderate-2 zone in this study contributed approximately 95% to the MVPA variable. Consequently, in contrast to McClain *et al.*,⁴⁰⁴ we do not recommend collapsing moderate-2 and vigorous activity zones into a single MVPA variable as a method to dilute greater variability from the moderate-2 zone. We would caution researchers that the creation of an MVPA variable does not always imply a reduced variability as suggested by others.⁴⁰⁴

Taken together these studies have shown that uni-axial accelerometer counts sampled during moderate intensities are more variable when collected at different body sites.^{95,404,448,449,663,689} However, none of these studies investigated the effect of body sites on moderate-to-vigorous time accumulated in bouts ≥ 10 min and on the compliance of subjects with PA public health guidelines. Consequently, contrary to the assertion by Trost *et al.* that the practical effect of different body sites on uni-axial

accelerometer output is negligible,⁶⁰⁷ we would argue that there is still uncertainty as to the practical effects of mounting uni-axial accelerometers at different body sites.

Although we could not calibrate the units before and during the field measurements, post-measurement variance analysis showed that 1.7% of the variability for total daily counts could be attributed to monitor units, which is in agreement with the 0.9% found by Welk *et al.* during multi-speed treadmill trials.⁶⁶⁶ The two-fold increase in variability compared with Welk *et al.* might be due to the greater time spent at low and moderate intensities in this sample and the free-living conditions. Importantly, the 14.5% to 20.1% variance for the trial-by-subject and monitor-by-trial-by-subject interaction reported by Welk *et al.*, suggests differences by subject due to clothing, posture and other anthropometric variations, which could be amplified during free-living trials due to lack of standardization.⁶⁶⁶ Moreover, Brage and associates have shown greater inter-unit variability at low to moderate intensities^{93,95} and it has been suggested that real anatomical differences such as body size, hip geometry and hip soft tissue deposition might explain acceleration differences between hip positions at lower movement intensities, specifically slow to normal walking.⁹⁵

We reanalyzed uni-axial accelerometer data from a recently reported variance component analysis¹³⁵ and found that accelerometer units accounted for 0% and 5.8% of the total variance of daily counts in rural and urban subjects, respectively. It is possible that the greater time spent in low-to-moderate activities (low accelerations) by the urban subjects would result in greater inter-instrument variability.^{93,95} This could in turn account for the increased accelerometer unit variability in urban subjects. Our results and those of others^{93,95,666} highlight the need to make post-measurement statistical adjustments for monitor units if individual calibration of units cannot be performed before and during field trials.⁹³⁻⁹⁵

Our finding of a substantial within-subject variance for the moderate-1 (bouts ≥ 10 min) in comparison with other variables is difficult to explain. We reanalyzed uni-axial accelerometer data recently reported for a larger rural sample out of which the current sample was drawn.¹³⁵ As with the current analysis, the between- and within-subject variance was 30% and 70%, respectively. Further analyses are required to

determine whether the variance distribution for this particular accumulated uni-axial accelerometer variable is due to a bias resulting from the creation of a variable accumulated from bouts of PA ≥ 10 min or is a reflection of a true behavioural characteristic of the subjects.

The strengths of the present pilot study are firstly the uniqueness of the analysis within a South African context. Secondly, this analysis provides reliability and variance estimates for a South African sample with particularly high occupational physical activity demands. Thirdly, this study has also been the first to show dramatically increased variability for time in moderate intensity variables accumulated in bouts ≥ 10 min. Further research is required to confirm this increased variability, and possible causes for this phenomenon. The weakness of this study is firstly that we could not differentiate between mechanical or anatomical causes for the increased variability of uni-axial accelerometer output at low to moderate intensities. However, no study to date has been able to quantify the separate contributions of mechanical and anatomical causes to increased variability across hip placement. Secondly, our sample size was limited when investigating the effects of monitor position variability on the compliance with public health PA guidelines.

In conclusion, this analysis has demonstrated that uni-axial accelerometer placement across hips has a greater effect on variability for derived duration variables in the moderate intensity range. This increased variability resulted in statistically small effects and future research should consider investigating the effects of uni-axial accelerometer placement on bouts of activity and the consequent compliance with PA guidelines. As part of quality control procedures, researchers should perform similar analyses when conducting field trials, and should either regularly calibrate individual accelerometer units or adjust statistically post-measurement when relating accelerometer output to a health outcome.

**CHAPTER 4: DEVELOPMENT OF A FOUR-ITEM SUBSISTENCE
ACTIVITY INDEX FROM INFORMATION ABOUT SUBSISTENCE
LIVING IN RURAL AFRICAN WOMEN. A DESCRIPTIVE, CROSS-
SECTIONAL INVESTIGATION.**

Data in this chapter has been published in the International Journal of Behavioral Nutrition and Physical Activity 6:75, 2009.

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INTRODUCTION

A host of PAQ are available for the quantification of human energy expenditure.⁴²⁶ PAQ, as an estimate of human energy expenditure, are routinely used to investigate the relationship between PA, morbidity and mortality.⁸⁷ While the majority of PAQ produce an energy expenditure output e.g. kilojoules, some investigators have used PAQ which consist of a single global question⁵⁶⁶ or which produce an index score.³²² The use of physical activity index scores has been used with some success in sub-Saharan Africa.^{324,428,558} However, the determination of public health guidelines from an index is problematic. If PA is not the main factor being investigated, but is rather a covariate that must be adjusted for, index scores are quite useful. A case in point is the investigation of the risk of various measures of adiposity in relation to non-communicable diseases such as hypertension, diabetes and dyslipidemia that adjusts for factors such as age, alcohol intake, smoking, energy intake and PA.⁶⁹⁴ In order to perform similar analyses on data collected in a rural field site¹³ during 1997¹⁵ for rural adult African females, a valid measure of PA had to be developed because the PAQ used in the original 1997 survey¹⁵ was not tested for validity in rural adult African females. The lack of validity might have displayed a “floor effect” such that important health enhancing PA behaviours were not probed.¹³⁰ For example, while vigorous work and leisure PA would be probed, low-to-moderate household and yard PA would be under-reported. Furthermore, any comparison of more recent data with the original survey,¹⁵ in terms of PA, would not be possible because the more recent surveys did not include the PAQ originally used. However, more recent surveys have included the same or very similar socio-demographic variables. Because the socio-demographic data contains variables which are directly or indirectly linked to a household’s subsistence level, and therefore PA level, we thought it possible to construct and validate a subsistence activity index (SAI). Therefore, this analysis aims to test the criterion validity of a SAI derived from socio-demographic variables, such as availability of motorized transportation, water and electricity supply and cooking methods, such that the SAI can be used as a suitable covariate in multivariate analyses.

4.1. METHODS

4.1.1. Study design

The validation of the SAI consisted of an analysis of two sets of data collected in the DHDSS field site.^{13,131} Part 1 of the analysis used data collected in 1997, which has been reported in detail elsewhere,¹⁵ and included anthropometry, blood biochemistry, resting systolic and diastolic blood pressure and socio-demographic information. Part 2 of the analysis used data collected in 2003/4 and included anthropometry, objectively measured PA, physical fitness (PF), resting blood pressure and socio-demographic information. Both studies obtained signed informed consent from all participants, and were approved by the Ethics Committee of the University of Limpopo.

4.1.2. Subjects

4.1.2.1. Part 1: 1997 data

For this analysis, a subset of 206 adult (30 to 55 yr), non-pregnant, rural African women, with complete data for variables relating to socio-demographics, anthropometry, blood biochemistry and resting blood pressure was selected from an existing dataset.¹⁵

4.1.2.2. Part 2: 2003/4 data

Data from a convenience sample of 138 adult (19 to 56 yr), non-pregnant, rural African women, permanently resident in the DHDSS site, were included in this analysis. The participants were contacted twice over an eight-day period. On the first occasion, subjects were recruited and completed the informed consent and a socio-demographic questionnaire. All interviews were conducted by trained, local, black female fieldworkers. After 10 min of seated rest, resting blood pressure was recorded. Thereafter anthropometric and PF measures were obtained. Trained female medical students conducted the anthropometric, resting blood pressure and PF measurements and entered data into spreadsheets. The first author was responsible for securing funding, the field worker training, accelerometer and heart rate monitor data management and overall data entry, data analysis and data

reporting. Finally, subjects were instructed on the required procedures for wearing the accelerometer. Eight days later the accelerometers were collected. Subjects received a small honorarium on completion of the study.

4.1.3. Anthropometric measurements

Part 1 and 2: 1997 and 2003/4 data

Standard anthropometric measures of stature (nearest 0.1 cm), body mass (nearest 0.1 kg) and waist circumference (WC, nearest 1 mm) were taken in duplicate with the subjects in light clothing and without shoes, and the average calculated. Additionally, in the 2003/4 sample, skinfold thicknesses (triceps, biceps, subscapular, suprailiac; nearest 1 mm, average of triplicate measurement) were measured according to standardised procedures.²⁷² From these measures body mass index ($BMI = \text{body mass} \div \text{stature}^2 = \text{kg.m}^{-2}$) and sum of skinfolds ($SSKF = \text{triceps} + \text{biceps} + \text{subscapular} + \text{suprailiac, mm}$) were calculated.

4.1.4. Biochemistry

Part 1: 1997 data

A registered nurse collected fasting blood samples. After having been seated for at least 15 min, 30 ml blood was drawn from each subject into either plain tubes or tubes containing ethylenediamine tetra-acetic acid or sodium fluoride. The blood samples were stored in a coolbox and then centrifuged within 5 h to prepare the plasma or serum. Aliquots were frozen at -70°C until analysed. The sodium fluoride plasma was used for measuring glucose and was analysed on a Technicon RA-XT, using reagents from Bayer Diagnostica, New York, USA. The remaining components were measured using Dimension ES and reagents from Dade Behring, USA. LDL-C was calculated using the Friedewald equation.²¹⁸ The inter-run coefficient of variation for glucose, T-C, HDL-C, and TG was 3.6%, 2.2%, 1.4% and 4.2%, respectively. The intra-run coefficient of variation for glucose, T-C, HDL-C, and TG was 4.2%, 2.3%, 1.8% and 3.1%, respectively.

4.1.5. Resting blood pressure

Part 1 and 2: 1997 and 2003/4 data

resting blood pressure (mmHg) was recorded with a mercury sphygmomanometer¹⁵ (Part 1: 1997 data) and a validated automated blood pressure monitor¹⁹⁴ (Part 2: 2003/4 data). Three readings were taken, and the average of the last two readings was used as a measure of resting blood pressure.

4.1.6. Physical Fitness Level

Part 2: 2003/4

$\text{VO}_{2\text{max}}$ was estimated using the submaximal, Siconolfi step test⁵⁴⁶ which has been shown to correlate well with measured $\text{VO}_{2\text{max}}$ ($r = 0.86$ to 0.92)^{254,546} and has been used in other indigenous populations.³²⁰ Briefly, the participants stepped on a 25.4 cm high bench for three min per stage for a maximum of three stages, or until their exercise heart rate for a stage exceeded 70% of age-predicted maximum heart rate ($220 - \text{age}$). Heart rate was measured using a heart rate monitor (Polar XTrainerPlus, Polar Electro OY, Finland). Exclusion criteria included a medical history of cardiovascular, respiratory, or severe muscular-skeletal disease or an unwillingness to perform the test. Trained female medical students supervised the testing.

4.1.7. Accelerometry

Part 2: 2003/4 data

To objectively quantify the PA of the subjects, single-plane accelerometers were worn for approximately seven days (mean: 6.95 days, minimum: 6.47 days, maximum: 7.50 days). The mean time for which counts were recorded ($\text{counts} \cdot \text{min}^{-1} > 0$) was $9.3 \text{ hr} \cdot \text{day}^{-1}$ (minimum: $5.4 \text{ hr} \cdot \text{day}^{-1}$, maximum: $12.9 \text{ hr} \cdot \text{day}^{-1}$). The MTI Actigraph accelerometer (model AM-7164-2.2, MTI Health Services, Fort Walton Beach, FL) is small and unobtrusive (5 cm x 4 cm x 1.5 cm, 43 g) and has been described in detail elsewhere.⁶⁶¹ In this study, the epoch duration was set at one min and the pedometer mode was activated. The accelerometer was worn on the right waist, securely attached to a nylon belt. The accelerometers could be removed for sleeping and bathing purposes by unclipping the nylon belt. The data was downloaded from the accelerometers onto an IBM-compatible personal computer via an interface unit, for further analysis. From at least five complete recording days, an average PA volume was defined as $\text{steps} \cdot \text{day}^{-1}$ and $\text{counts} \cdot \text{day}^{-1}$, and PA intensity

patterns as min.day^{-1} of sedentary, light and moderate-to-vigorous activity. The cut-points for moderate (3-6 METs, 1 MET = 1 Metabolic Equivalent = $3.5 \text{ mlO}_2.\text{kg}^{-1}.\text{min}^{-1} = 1 \text{ kcal.kg}^{-1}.\text{hr}^{-1}$) and vigorous (>6 METs) activity was $574 \text{ counts.min}^{-1}$ and $4945 \text{ counts.min}^{-1}$, respectively.⁵⁸¹ Sedentary behaviour was defined as $\text{counts.min}^{-1} = 0$, and included lying, sitting and standing still. Light activity was defined as $\text{counts.min}^{-1} > 0$ but less than 574. From the accelerometry data we determined compliance with two PA public health guidelines. The ACSM/CDC guidelines recommend moderate-to-vigorous PA of 30 min.day^{-1} , at least 5 days.wk^{-1} , accumulated in bouts of $\geq 10 \text{ min}$.⁴⁷³ The IOM guidelines recommend moderate-to-vigorous PA of 60 min.day^{-1} , at least 5 days.wk^{-1} , accumulated in bouts of $\geq 10 \text{ min}$.⁵³⁴

4.1.8. Subsistence Activity Index

The SAI was derived from four questions, found within a socio-demographic questionnaire which was used in the original survey conducted in 1997¹⁵ and the more recent 2003/4 sample. The questions probed availability of electricity in the dwelling, collection of water, use of wood for cooking, and access to a motor vehicle within the household.

The rationale for using these particular questions was that within this particular community, at present, much of the PA performed by women revolves around housework and yard work. Communal lands are available for planting of crops, such as maize and some vegetables, and cattle grazing. The lack of electricity in the dwelling precludes the use of labour saving devices such as washing machines and vacuum cleaners, while a supply of electricity could encourage greater sedentary activity due to electronic devices such as television.^{271,336} The use of wood for cooking is still common and requires the collection (saws, axes) and transport (head panning, wheelbarrows) of the raw material or purchasing of wood from sellers coming to the villages. If water is not available in or around the dwelling, water is collected in containers and transported principally through head panning or wheelbarrows. Journeys to the local store, clinic, communal fields, and to bus or taxi stops are completed on foot, if there is no access to motor vehicle transport within the household.⁵⁷ Leisure activities prevalent in urban settings are not encountered in the DHDSS.

Consequently, we felt that these four questions provided a reasonable categorical estimate of the most common activities performed by the majority of women in the DHDSS. The questions, possible responses and scoring are set out in Table 4.1.

Table 4.1. The questions, responses and scoring of the derived Subsistence Activity Index.

Question and Responses		Scoring
Do you have electricity in the house (Yes/No)		Yes = 0, No = 1
Do you use wood for cooking? (Yes/No)		Yes = 1, No = 0
Does any person in your household own a motor vehicle? (Yes/No)		Yes = 0, No = 1
How is your water supplied? (Select one)		
	Tap inside the house	Yes = 0
	Tap outside the house	Yes = 0
	Shared tap	Yes = 1
	Communal tap	Yes = 1
	Water truck	Yes = 1
Total score =		Sum of responses

A score of 1 was allocated to the option which would more likely result in greater energy expenditure. The lowest and highest scores possible are zero and four, respectively, which we translated into three arbitrary categories; low subsistence level (total score ≤ 2 , low activity level), medium subsistence level (total score = 3, medium activity level) and high subsistence level (total score = 4, high activity level).

4.1.9. Statistical analysis

To test the validity of our SAI, the trend (linear and non-linear) across the three SAI categories was tested for continuous measures (adiposity, blood biochemistry, resting blood pressure, PA volumes and intensity patterns), and frequencies (adherence to PA public health guidelines). One-way analysis of variance and univariate general linear model analyses (age and BMI or WC as covariates where required) were used for continuous variables across SAI categories. Independent t-tests examined possible differences between the two datasets. For categorical data, a Chi-square test for trend was used across SAI categories, and independent tests of proportions examined possible differences between the two data sets.¹⁸ We expected inverse trends for measures of adiposity, glucose, T-C, TG, LDL-C, resting blood pressure, sedentary activity, and light activity with increasing SAI index. HDL-C, PF, PA volumes, moderate-to-vigorous activity, and adherence to public health guidelines were expected to increase with increasing SAI index. For comparative

purposes we also performed correlational analyses (Kendall's τ) between the SAI index and continuous criterion measures, namely adiposity, PF, glucose, TG, T-C, LDL-C, HDL-C, PA volumes, sedentary activity, light activity, moderate-to-vigorous activity, and adherence to public health guidelines. Thereafter, Kendall's τ was converted to Pearson's r .⁶⁴⁷ First-order partial correlation coefficients were calculated as required. Where necessary continuous data were transformed (\log_e) and expressed as a geometric mean. Data were analysed using appropriate statistical software (SPSS Inc. SPSS Statistical Software: Release 17.0.0 SPSS Corp, Chicago, IL, 2008). Significance for all inferential statistics was set at $p < 0.05$, and 95%CI were constructed for means and proportions.

4.2. RESULTS

Subject characteristics for both parts of the analysis are reported in Table 4.2. Not all the subjects completed the fitness test due to uncontrolled hypertension, epilepsy or personal reasons ($n=7$). Noticeable are the significant increases in electricity supply (53%, $p=0.0002$) within dwellings and educational achievement (31.4%, $p<0.0001$) from 1997 to 2003/4 (Table 4.2). SAI scores tended to be evenly distributed across subsistence level categories for the 1997 data, but tended to aggregate toward the low-to-medium subsistence level categories for the 2003/4 data. There was a significant decrease in the high subsistence SAI level category from 1997 to 2003/4 ($p<0.05$) (Table 4.2).

4.2.1. Part 1: 1997 data

We found no statistically significant linear trend between SAI level and age ($p=0.8852$) or educational achievement of at least Gr. 8 (Grade 8: first year of secondary or high school, $p=0.0516$). Self reported diagnosis with, or on medication for, hypertension and/or diabetes was linearly related to SAI level ($p=0.0180$). However, using objective measures of resting blood pressure and glucose levels we found no linear trend between hypertensive ($\geq 140/90$ mmHg)¹⁵ and/or diabetic (fasting glucose ≥ 7.0 mmol.l⁻¹) states¹⁵ and SAI level ($p=0.4093$). Age did not differ significantly between any of the SAI levels ($p=0.2121$).

Table 4.2. Subject physical and socio-demographic characteristics.

	Part 1: 1997 data (N = 206)	Part 2: 2003/4 data (N = 138)
Health and Socio-demographic*		
Diagnosed with hypertension and/or diabetes	31.4 (25.2 to 38.3)	21.0 (15.0 to 28.6) **
Prevalence of body mass index ≥ 30 kg.m ⁻²	30.6 (24.7 to 37.2)	33.3 (26.0 to 41.6)
Prevalence of waist circumference ≥ 88 cm	36.4 (30.1 to 43.2)	35.5 (28.0 to 43.8)
Achieved educational level of Gr. 8	23.7 (18.3 to 30.2)	55.1 (46.7 to 63.1) **
Electricity inside house	34.0 (28.8 to 39.6)	87.0 (80.3 to 91.6) **
Wood used for cooking purposes	83.3 (78.8 to 87.3)	89.9 (83.7 to 93.9)
One or more persons owns a motor vehicle	18.9 (14.8 to 23.8)	16.7 (11.4 to 23.8)
Water supplied by tap in or around dwelling	52.0 (46.2 to 57.7)	56.5 (48.2 to 64.5)
Subsistence Activity Index*		
Low subsistence level (score ≤ 2 , low activity level)	39.3 (32.9 to 46.1)	19.6 (13.8 to 27.0) **
Medium subsistence level (score = 3, medium activity level)	25.2 (19.8 to 31.6)	57.3 (48.9 to 65.2) **
High subsistence level (score = 4, high activity level)	35.4 (29.2 to 42.2)	23.2 (16.9 to 30.9) **
Anthropometry and fitness		
Age (yr)	43.6 (42.6 to 44.6)	36.3 (34.6 to 37.9) **
Body mass index (kg.m ⁻²)	26.8 (25.9 to 27.6)	26.9 (25.8 to 27.9)
Waist circumference (cm)	83 (82 to 85)	83 (81 to 85)
Sum of four skinfolds (mm) †	-	65 (59 to 71)
VO _{2max} (mlO ₂ .kg ⁻¹ .min ⁻¹) ‡	-	26.7 (25.6 to 27.7)
Blood biochemistry		
Blood glucose (mmol.l ⁻¹) †	5.20 (4.95 to 5.45)	-
Triglyceride (mmol.l ⁻¹) †	1.05 (0.90 to 1.01)	-
Total cholesterol (mmol.l ⁻¹)	4.52 (4.37 to 4.67)	-
HDL-cholesterol (mmol.l ⁻¹)	1.19 (1.16 to 1.21)	-
LDL-cholesterol (mmol.l ⁻¹) †	2.69 (2.56 to 2.82)	-
Resting blood pressure		
Systolic blood pressure (mmHg)	129 (126 to 132)	120 (117 to 122) **
Diastolic blood pressure (mmHg)	84 (83 to 86)	77 (75 to 79) **
Accelerometry		
Counts.day ⁻¹ (x 1000)	-	411 (390 to 432)
Steps.day ⁻¹ (x 1000)	-	13.5 (13.0 to 14.1)
Sedentary activity (min.day ⁻¹)	-	797 (780 to 814)
Light activity (min.day ⁻¹)	-	390 (375 to 405)
Moderate-to-vigorous activity (min.day ⁻¹)	-	253 (241 to 266)
Adherence to public health guidelines¹		
ACSM/CDC Guidelines §	-	96.4 (91.8 to 98.4)
IOM Guidelines	-	69.6 (61.4 to 76.6)

values are reported as mean (95%CI) except * % (95%CI) and † geometric mean (95%CI); ‡ n = 131; § ACSM/CDC guidelines: moderate-to-vigorous PA of 30 min.day⁻¹, at least 5 days.wk⁻¹, accumulated in bouts of ≥ 10 min; || IOM guidelines: moderate-to-vigorous PA of 60 min.day⁻¹, at least 5 days.wk⁻¹, accumulated in bouts of ≥ 10 min; ** significant differences between the two datasets, $p \leq 0.05$.

The trend analysis for age-adjusted continuous criterion variables is reported in Table 4.3. Significant age-adjusted linear decreases in BMI ($p=0.0091$), WC ($p=0.0003$) and glucose ($p<0.0001$) with increasing SAI were found, while the age-adjusted linear trend for LDL-C did not quite reach statistical significance ($p=0.0650$). The linear trend for glucose remained significant after adjusting for age and BMI or

age and WC ($p < 0.0001$). Generally, other criterion variables were relatively constant across SAI levels. Non-linear trends for continuous variables across SAI categories were not significant ($p > 0.2$). Correlational analysis between the SAI score and continuous criterion variables mirrored the findings of the linear analyses.

Table 4.3. Part 1 (1997 dataset): Linear trend across three SAI categories for continuous variables.

	Subsistence Activity level			Significance level
	Low	Medium	High	
	(SAI score ≤2) (n = 81)	(SAI score =3) (n = 52)	(SAI score =4) (n = 73)	
Anthropometry and fitness				
Body mass index (kg.m ⁻²)	28.1 (26.8 to 29.5)	26.4 (24.7 to 28.1)	25.5 (24.1 to 27.0)	0.0091 †
Waist circumference (cm)	87 (85 to 90)	82 (79 to 86)	80 (77 to 83)	0.0003 †
Resting blood pressure				
Systolic blood pressure (mmHg)	132 (128 to 137)	128 (123 to 134)	126 (122 to 131)	0.0754
Diastolic blood pressure (mmHg)	85 (82 to 87)	84 (81 to 88)	84 (82 to 87)	0.7305
Blood biochemistry				
Blood glucose (mmol.l ⁻¹) *	5.96 (5.54 to 6.41)	4.95 (4.52 to 5.42)	4.62 (4.28 to 4.99)	<0.0001 †
Triglyceride (mmol.l ⁻¹) †	0.96 (0.88 to 1.05)	0.96 (0.86 to 1.07)	0.94 (0.86 to 1.03)	0.7668
Total cholesterol (mmol.l ⁻¹)	4.67 (4.44 to 4.90)	4.41 (4.12 to 4.70)	4.43 (4.19 to 4.68)	0.1631
HDL-cholesterol (mmol.l ⁻¹)	1.19 (1.15 to 1.22)	1.18 (1.13 to 1.23)	1.20 (1.15 to 1.24)	0.7563
LDL-cholesterol (mmol.l ⁻¹) *	2.85 (2.64 to 3.08)	2.60 (2.36 to 2.86)	2.57 (2.37 to 2.79)	0.0650

values are reported as age-adjusted mean (95%CI) except * age-adjusted geometric mean (95%CI); † significant linear trend for low-to-high active.

Significant coefficients were obtained for BMI ($r = -0.24$, $p = 0.0037$), WC ($r = -0.30$, $p = 0.0004$) and glucose ($r = -0.47$, $p < 0.0001$). The association between SAI and glucose remained significant, even after adjusting for BMI ($r = 0.20$, $p = 0.0034$). Age was not significantly related to either glucose ($r = 0.09$, $p = 0.2105$) or the SAI score ($r = -0.03$, $p = 0.6893$).

4.2.2. Part 2: 2003/4 data

We found no linear trend between SAI level and age ($p = 0.4919$), educational achievement of at least Gr. 8 ($p = 0.1644$), or diagnosis with or on medication for hypertension and/or diabetes ($p = 0.6741$). Age did not differ significantly between any of the SAI groups ($p = 0.1292$). The trend analysis for continuous (age adjusted) and categorical criterion variables is reported in Table 4.4. After adjustment for age, SSKF decreased significantly with increasing SAI level ($p = 0.0322$) and VO_{2max} increased significantly with increasing SAI ($p = 0.0190$). Other measures of adiposity tended to decrease with greater SAI level but not significantly so ($p > 0.08$). PA volumes (counts.day⁻¹ and steps.day⁻¹), moderate-to-vigorous activity levels and

adherence to IOM Guidelines showed significant linear trends, and in the expected direction ($p < 0.03$). Sedentary behaviour was inversely related to SAI, but did not quite reach statistical significance ($p = 0.0806$). Non-linear trends for continuous variables across SAI categories were not significant ($p \geq 0.2$). Correlational analysis between the SAI score and continuous criterion variables mirrored the findings of the linear analyses. Significant coefficients were obtained for VO_{2max} ($r = 0.21$, $p = 0.0466$), counts.day⁻¹ ($r = 0.26$, $p = 0.0113$), steps.day⁻¹ ($r = 0.23$, $p = 0.0292$) and moderate-to-vigorous activity (min.day⁻¹) ($r = 0.27$, $p = 0.0085$). Age was not significantly related to the SAI score ($r = 0.06$, $p = 0.5761$).

Table 4.4. Part 2 (2003/4 dataset): Linear trend across three SAI categories for continuous and categorical variables.

	Subsistence Activity level			Significance level
	Low (SAI score ≤2) (n = 27)	Medium (SAI score =3) (n = 79)	High (SAI score =4) (n = 32)	
Anthropometry and fitness				
Body mass index (kg.m ⁻²)	28.1 (25.8 to 30.4)	27.1 (25.8 to 28.4)	25.2 (23.1 to 27.3)	0.0617
Waist circumference (cm)	86 (81 to 91)	84 (81 to 87)	80 (75 to 84)	0.0703
Sum of four skinfolds (mm) *	74 (60 to 90)	67 (59 to 75)	55 (45 to 66)	0.0322 ‡
VO _{2max} (mlO ₂ .kg ⁻¹ .min ⁻¹)	25.7 (23.8 to 27.5) ‡	26.2 (25.1 to 27.3) ‡	28.7 (27.0 to 30.5) ‡	0.0190 ‡
Resting blood pressure				
Systolic blood pressure (mmHg)	119 (114 to 125)	120 (116 to 123)	120 (115 to 125)	0.8387
Diastolic blood pressure (mmHg)	78 (74 to 82)	77 (74 to 79)	78 (74 to 81)	0.9611
Accelerometry				
Counts.day ⁻¹ (x 1000)	364 (317 to 411)	409 (381 to 436)	457 (414 to 501)	0.0044 ‡
Steps.day ⁻¹ (x 1000)	12.3 (11.0 to 13.6)	13.6 (12.9 to 14.4)	14.3 (13.1 to 15.5)	0.0265 ‡
Sedentary activity (min.day ⁻¹)	828 (789 to 866)	793 (770 to 815)	781 (746 to 817)	0.0806
Light activity (min.day ⁻¹)	387 (354 to 420)	396 (377 to 416)	377 (346 to 408)	0.6755
Moderate-to-vigorous activity (min.day ⁻¹)	225 (198 to 253)	251 (235 to 267)	282 (256 to 307)	0.0040 ‡
Adherence to public health guidelines †				
ACSM/CDC Guidelines ‡	96.0 (80.5 to 99.3)	98.5 (91.8 to 99.7)	93.8 (83.2 to 97.9)	0.5678
IOM Guidelines §	51.9 (34.0 to 69.3)	70.9 (60.1 to 79.8)	81.3 (64.7 to 91.1)	0.0157 ‡

values are reported as age-adjusted mean (95%CI) except for * age-adjusted geometric mean (95%CI) and † % (95%CI); ‡ ACSM/CDC guidelines: moderate-to-vigorous PA of 30 min.day⁻¹, at least 5 days.wk⁻¹, accumulated in bouts of ≥ 10 min; § IOM guidelines: moderate-to-vigorous PA of 60 min.day⁻¹, at least 5 days.wk⁻¹, accumulated in bouts of ≥ 10 min; †† n = 26; ** n = 75; †† n = 30; †† significant linear trend for low-to-high active.

4.3. DISCUSSION

The principal finding of this analysis was that a three-point SAI derived from four questions within a socio-demographic questionnaire, was significantly associated with a number of criterion measures namely adiposity, fasting blood glucose, VO_{2max} and raw and derived- accelerometry output. Furthermore, the relationship of a

number of other criterion variables with the SAI was in the expected direction, but did not reach statistical significance. These results suggest that the derived SAI is valid for broadly categorizing levels of PA for this particular population, at this particular time. Importantly, this analysis was novel because a PA measure had to be constructed and validated from socio-demographic data collected in 1997 and 2003/4, so that the SAI could be used as a covariate in an analysis of data collected in 1997.¹⁵ In other words, the validation analysis was performed on two datasets separated by six yr.

The variables we chose to comprise the SAI affect the possession or not of a number of assets which in turn directly or indirectly decrease or increase PA behaviour and hence energy expenditure levels. These variables do not narrowly confine their influence within a household to a small number of tasks which might affect only a few members of the household. Rather, the effect is fundamental and pervasive such that the entire household is affected in terms of PA choices and behaviours and consequent energy expenditure levels.^{57,271,336} Moreover, our experience has been that in agrarian households, workload is spread relatively evenly throughout the female population, unless very ill or incapacitated. The chores might not be all equal in nature, but rather that the general activity level is higher in that household, especially so for women. These subsistence tasks performed by the household are usually light-to-moderate in intensity, spread out over a large portion of the day which is in contrast to Western productivity which requires high bursts of energy over relatively shorter periods of time.⁴⁶⁹ Moreover, much of the decline in PA in industrialised settings has been through the reduction in subsistence PA, namely occupation, household and yard PA.³⁰⁶ The reduced subsistence PA, and resultant positive energy balance, in highly industrialised, urbanised settings has led to a concomitant rise in obesity and various chronic diseases of lifestyle of epidemic proportions.³⁰⁶

The results highlight the relatively early stage of epidemiological change in which this community finds itself. The implication is that the SAI would not be valid in yr to come as PA behaviours shift to more sedentary choices and patterns ³⁷⁸. Investigations in developing economies have found a wide range of PA levels based

on occupation and gender,^{323,376} which is not the case in industrialised countries where leisure-time pursuits tend to dominate PA choices.⁵⁴⁴ Because criterion validity was established for 1997 and 2003/4 datasets, it would seem that PA, driven by subsistence demands, have not altered markedly over this six year period.

The changes in electricity supply and educational achievement are probably because of the extensive electrification projects within rural communities by the national electricity supplier and the national imperative to extend education within all communities in child and adult populations. The significantly lower diabetes and/or hypertension prevalence for the 2003/4 sample compared with the 1997 sample is likely due to the convenience sampling and selection criteria, and also because the 2003/4 sample is significantly younger than the 1997 sample. resting blood pressure is significantly higher in the 1997 sample compared with the 2003/4 sample and is probably due to sampling methods and selection criteria, the subject age differential between the two datasets, and because different instruments were used to measure resting blood pressure.

Our results are in accord with other work which has shown that rural women carry a relatively heavy work burden, particularly with respect to household and yard work, and aspects of farming.³⁵⁶ Likewise, Walker *et al.* have noted the physically active lifestyle of rural African women.⁶⁴⁶ Surprisingly, similar PA patterns have been reported for urban African women in an informal settlement.⁶¹² It is plausible that the PA levels of these women is comparable to that of rural residents, considering that informal settlements often lack modern amenities, much like rural settings⁶¹². Paradoxically, some studies have found deep rural African women to be less physically active than women resident on farms or in informal settlements.³²³ Generally, these studies would seem to suggest that our choice of questions provides a fairly robust, albeit crude, measure of the PA demands placed on rural African women. Indeed, our findings bear out the observation of Baranowski as to the “robustness of the phenomenon” with regards to the quantification of PA.³⁶ This does not imply that researchers need not rigorously validate PA instruments for specific populations, but rather that meticulously investigated validity, particularly content validity, invariably results in robust measures of PA. Although we did not test

reliability, we would argue that the questions are logical, unambiguous, easily understood within any ethnic or language context, and that the aspects which the questions probe are stable over time, such that reliability would be expected to be high. In this regard Kruger *et al.* found an intra-class correlation coefficient of 0.88 with a more extensive SAI administered to rural and urban subjects.³²² However, further reliability studies would need to be conducted to test our assertion.

The use of PA indexes in other studies in sub-Saharan Africa have shown similar trends, albeit that none of these studies used trend analysis across ordered groups, which is the recommended statistical technique for such data.¹⁸ Generally, these studies have used analysis of variance with *post hoc* analysis, and correlation analysis. Morrison *et al.* found significant associations between an eight-point PA index probing leisure-time PA and measures of fitness and adiposity in a sample of 1015 Caucasian Zimbabweans.⁴²⁸ The retrospective analysis by Sparling *et al.* used data obtained from 212 urban African males.⁵⁵⁸ The PA index probed within-work and after-work PA categories. Both categories consisted of three groupings (low-to-high). The trend between the PA index and measures of adiposity, blood pressure and serum lipids was not as pronounced as might be expected. In fact, the most favourable blood pressure and serum lipid profiles were found within low-to-moderate PA levels. The data of Sparling *et al.* reveals no significant linear trends in within-work PA for measures of adiposity, blood pressure or serum lipids ($p \geq 0.1495$).⁵⁵⁸ However, for age-adjusted data, the trends were stronger for after-work PA, but did not reach significance ($p \geq 0.0782$).⁵⁵⁸ Kruger *et al.* investigated the validity and reliability of a more extensive PA index in 206 rural and urban Africans³²². Significant associations were found between the PA index score and measures of adiposity. Furthermore, adiposity in the most active quartile was significantly lower than the least active quartile. Similarly, energy intake was significantly higher in the most active quartile. Results provided in the Kruger *et al.* paper allowed us to determine that significant linear trends ($p \geq 0.0006$) exist for measures of adiposity and energy intake across the four quartiles of activity.³²²

Although linear trend analysis across ordered groups is the recommended statistical technique for such data¹⁸ we have reported correlation coefficients for comparative

purposes. SAI criterion validity correlation coefficients (median: $r=0.24$, range: $r=0.20$ to $r=0.30$), fell within the range of values reported for a number of self report physical activity questionnaires ($r=0.14$ to $r=0.53$)⁵³³ but did not reach the range of values reported for the recently validated IPAQ¹⁴¹ and the GPAQ,²⁷ ($r=0.31$ to 0.52). Considering the length and detailed nature of the comparative questionnaires,^{27,141,533} the SAI criterion validity correlation coefficients were remarkably large.

The strengths of the study were firstly that novel data was reported from the sub-Saharan African region, specifically for accelerometry and physical fitness, in an under-reported segment of the population, namely rural African women. Secondly, the study highlights the fact that the workload of rural African women is influenced to a large extent by economic and developmental variables. Thirdly, significant associations were found in both datasets, using a variety of indirect and direct criterion variables. Lastly, despite the constraints imposed by the *post hoc* development and testing of the SAI, the criterion validity coefficients were reasonable when compared with results from other validation studies.

Weaknesses of the study were firstly the limitations imposed by the datasets in terms of available variables, such that we could not conduct more in-depth analyses on other factors that might affect the workload for household and individual female members of the household. We would thus caution against the use of this particular SAI score as a general measure of PA in rural African women without further testing and refinement to address more fully aspects of internal and external validity. Secondly, we could not address the energy intake levels across the SAI levels, and thus energy balance with the concomitant influences on anthropometric indices and blood biochemistry. Lastly, although we did compare results between the two datasets, the comparison is limited because both samples were convenience samples selected according to different criteria.

In conclusion, this analysis suggests that a simple SAI, derived from socio-demographic variables, is a valid but probably temporary measure of PA within a specific population of rural African women, and can be included as a covariate in multivariate analyses using a 1997 dataset.

**CHAPTER 5: PATTERNS AND VOLUMES OF ACCELEROMETRY-
MEASURED PHYSICAL ACTIVITY IN RURAL AND URBAN BLACK
SOUTH AFRICAN FEMALES IN THE LIMPOPO PROVINCE, SOUTH
AFRICA**

Data in this chapter has been accepted for publication in the Journal of Physical Activity and Health, 2012.

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5.1. INTRODUCTION

Lack of PA is considered a leading risk factor for chronic diseases of lifestyle and has been estimated to contribute 5% and 21-22% to stroke and ischaemic heart disease, respectively in low- and high-mortality developing regions.¹⁹⁸ The SACRACG attributed 20-30% of ischaemic heart disease, ischaemic stroke and Type 2 diabetes mellitus to a lack of PA.³⁰⁰ Moreover, lack of PA is considered a significant etiological factor in the epidemiological transition, which is characterized by increasing obesity and chronic diseases of lifestyle.^{306,496} Of concern is the prevalence of obesity in rural and urban black South African women; 21.0% and 33.8%, respectively.¹⁵⁶

However, to date much of the evidence regarding PA levels within African contexts has been obtained through self-report measures^{5,15,324} and only recently have objective measures of PA been employed in African settings.^{29,58,119,127,128,132,168,371} From a South African perspective, the possibility of significant physical activity/inactivity misclassification as a result of self-report measures has been raised.¹³⁰ Recent reports from a highly industrialized setting revealed discrepancies between objective and subjective measures of PA.⁶⁰⁶ In agreement, objective monitoring of PA within a rural South African setting suggests that self-report measures are over-reporting sedentarism and under-reporting physically active behaviours.^{127,128} Current self-report measures typically probe leisure time PA, which although predominant in industrialized settings, do not accurately assess occupational activity, non-recreational leisure activity and walking which prevail in African settings.^{128,208,555} Moreover, the preoccupation with typical leisure-type pursuits in industrialized settings, has led to the adoption of accelerometer intensity thresholds (≥ 1952 counts.min⁻¹) which ignore less ambulatory, moderate intensity lifestyle activities that accumulate counts between 500 – 1000 counts.min⁻¹.^{392,472} A better understanding of accelerometer-measured PA count distribution throughout the range of count bands would provide greater insight into not only the PA peculiarities of different populations, but also how discrepancies are occurring between self-report and objective measures of PA. There is a dearth of data

describing PA count distribution for the sub-Saharan African region, and specifically within the South African context.

The objectives of this paper were to describe the distribution of uni-axial accelerometer measured PA counts across a number of count bands in a rural and urban setting and the implications of two moderate PA intensity thresholds.

5.2. METHODS

5.2.1. Study design

The present investigation consisted of an analysis of two sets of data. Firstly, we used an urban, adult female sample from a larger convenient dataset which tested the validity of the IPAQ in adult, black South Africans, and which has been reported elsewhere.^{78,134,141} Secondly, data was obtained from a convenient rural sample which surveyed adult, black females in the DHDSS^{13,14,131} of which part of the accelerometry data is reported elsewhere.¹²⁸ Participants were recruited by fieldworkers through office-to-office visits for the urban sample and house-to-house visits for the rural sample, at common meeting places, and through general mouth-to-mouth promotion of the survey. For this analysis, only the anthropometry and accelerometry data from the two datasets were considered.

5.2.2. Study protocol

Adult black females resident in urban or rural areas of the Limpopo Province, South Africa were contacted twice over an eight to nine day period. On the first occasion, participants were recruited, completed a socio-demographic questionnaire and provided anthropometric data. All interviews, anthropometric measures and accelerometer placement were conducted by trained male and female field workers. The first author was responsible for securing funding, field worker training, the accelerometer data management and overall data entry, data analysis and data reporting. Anthropometric measures included body mass (kg) and stature (cm) allowing the calculation of body mass index (BMI, kg.m^{-2}). Finally, participants were instructed on the necessary procedures for wearing the accelerometer. Eight to nine days later the accelerometers were collected. Participants received a small

honorarium on completion of the study. Both studies obtained signed informed consent from all participants, and were approved by the Ethics Committee of the University of Limpopo.

5.2.3. Participants

Rural, adult females resident in the DHDSS, were conveniently recruited (n=272) during 2003-2004. For the most part these participants performed subsistence tasks such as housework, fetching wood and water, and walking as a means of transport. Urban, adult female academic staff, support staff and students of the University of the Limpopo (Turfloop Campus) and residents (office workers, teachers) from the surrounding community (Mankweng) and nearby city (Polokwane) (n=16) were conveniently recruited during 2000. For the most part, these participants performed tasks typical of office workers, with long periods of sedentary activity (sitting, standing quietly).

5.2.4. Accelerometry

To objectively quantify the PA, participants were asked to wear single-plane accelerometers for six to seven complete days. The CSA model 7164 and MTI model AM-7164-2.2 are both products of Actigraph, LLC, Pensacola, FL, USA (formerly Computer Science Applications, Inc. Shalimar, FL and MTI Health Services, Fort Walton Beach, FL). The accelerometers are small and unobtrusive (5 cm x 4 cm x 1.5 cm, 43 g) and have been described in detail elsewhere.⁶⁶¹ Unlike the model 7164, the model AM-7164-2.2 is also capable of a step count output. The CSA model 7164 was used during the urban trial and the MTI model 7164-2.2 was used during the rural trial. Recent work suggests small but practically insignificant output differences between the models used in this analysis.⁵²⁸ For both these models, the epoch duration was set at one min. The accelerometers were worn on the right waist, securely attached to a nylon belt and removed for sleeping and bathing purposes by unclipping the nylon belt. The min-by-min data were downloaded from the accelerometers onto an IBM-compatible personal computer via an interface unit, for further analysis using specialized software (MAH/UFFE Analyzer version 1.9.0.3; www.mrc-epid.cam.ac.uk).

Physical activity counts were defined as total counts (TC, counts.day⁻¹) and average counts (total counts ÷ registered time, counts.min⁻¹.day⁻¹). Physical activity volumes (min.day⁻¹) of sedentary, light, moderate and vigorous activities were derived using previously defined cut-points.^{141,388,390} Sedentary (SED) and light (LGT) activities (lying, sitting, standing quietly, light activity) were classified as 0-99 counts.min⁻¹ and 100-759 counts.min⁻¹, respectively. For moderate activity (3-6 METs, 1 MET = 1 Metabolic Equivalent = 3.5 mlO₂.kg⁻¹.min⁻¹ = 1 kcal.kg⁻¹.hr⁻¹) a distinction was made between activities requiring less ambulation (MOD1: house work, yard work, 760-1951 counts.min⁻¹) and predominantly ambulatory activities (MOD2: walking, 1952-5724 counts.min⁻¹). Activities, such as running, which record ≥5725 counts.min⁻¹ were defined as vigorous (VG, >6 METs). Because of the low volume and highly skewed distribution of the recorded VG activity (rural: 0.5 ±1.4 min vs. urban: 0.6 ±1.4 min) we also created the following categories: MOD1VG (≥760 counts.min⁻¹) and MOD2VG (≥1952 counts.min⁻¹). The categories for the amount of activity accumulated in bouts of ≥10 min (bouts separated by >1 min) for counts.min⁻¹ ≥760 (MOD1VGbt) and counts.min⁻¹ ≥1952 (MOD2VGbt) were also derived.

To be considered a valid day, registered time was ≥600 min (10 hr) out of 24 hr for the raw data. The first and last days of monitoring were ignored because these were incomplete days, and zero runs lasting ≥60 min were excluded from this initial data screen. Because participants were not requested to record daily wear times of the accelerometer, an arbitrary daily wear time of 04H00-24H00 (20 hr) was assumed. From time use data, 95% of South Africans ≥20 yr of age are sleeping by 24H00.¹¹⁸ Television viewing peaks at 20H30 (21%) and declines to 1% by 24H00. By 04H00 94% are sleeping and with 0% television viewing, and by 05H00 18% are already awake.¹¹⁸ Consequently, to maximize the activity counts recorded during valid days, and to minimize sleep time, all subsequent analyses were based on this 20 hr wear time, excluding the first and last days of monitoring but including all zero runs ≥60 min. All participants with at least one valid day were included.

5.2.5. Power analysis

A power analysis of unadjusted raw (counts) and derived (min) accelerometry data (mean±sd, independent t-test, α = 0.05, 1-β = 0.80, two tailed, rural: n=263, urban:

n=16) yielded required delta values of 89229 for raw counts and 8 min to 60 min for derived accelerometry indices. The observed/required delta for TC, SED, MOD1 and MOD1VGbt were 88791 counts/89229 counts, 66 min/60 min, 70 min/38 min and 22 min/23 min, respectively. The observed/required delta for LGT, MOD2VG and MOD2VGbt were 7 min/ 37 min, 4 min/20 min and 3 min/8 min, respectively. This analysis suggested that the available sample sizes would provide sufficient power on key accelerometry data to warrant further analyses. We evaluated available sample sizes using GraphPad StatMate version 2.00, GraphPad Software, California, USA, 2004.

5.2.6. Statistical analysis

Each participant had multiple records by hour for each valid day. From this multiple-record dataset an average hourly profile for each participant was created in a separate dataset (20 records per participant). A second dataset was created from the main dataset to obtain an average day for each participant (1 record per participant). Because not all participants contributed equally to all days of the week, a third dataset was created which aggregated data by day of the week.

Descriptive statistics comprised residence-specific means and 95% confidence intervals (95%CI) or one SD. Independent t-tests and simple analysis of variance were used to compare descriptive variables across residence status and variables across days of valid accelerometer wear. Univariate and repeated measures general linear models were used to compare rural and urban counts and volumes by hour, by weekday and average day, adjusting for age and BMI. *Post hoc* multiple comparison analyses (Sidak's t-test) assessed group differences. Multiple linear regression models, using backward selection, were used to examine the relative importance of PA volumes (LGT, MOD1, MOD2VG) to TC by residence. In addition to PA volumes, age, BMI and accelerometer unit number were included in all initial models. Significance for variable entry into and exit out of the model were set at $p=0.05$ and $p=0.1$, respectively. Residence-specific incidence rates of bouts of hourly step intensity and bouts ≥ 10 min for MOD1VGbt and MOD2VGbt categories were expressed as bouts per 24 person-hr, and 95%CI were calculated adjusting for recurrent events.²³² Poisson regression models, with robust variance estimation,

were used to examine the odds of achieving bouts ≥ 10 min for MOD1VGbt and MOD2VGbt categories.⁶³⁴ Age, BMI and TC were entered as covariates. To investigate the influence of MOD1VGbt and MOD2VGbt categories on PA adherence prevalence (≥ 30 min.day⁻¹, 5 days.wk⁻¹),²⁵⁷ a Bayesian approach was used to include the information from all participants with one or more valid days.⁶⁰⁶

Data were analysed using appropriate statistical software (SPSS version 17.0.3, SPSS Inc., Chicago, USA, 2009 and Stata/SE version 11.1, StataCorp LP, Texas, USA, 2009). Significance for all inferential statistics was set at $p < 0.05$.

5.3. RESULTS

Rural (n=263) and urban (n=16) participants accumulated 29 300 person-hr and 1 540 person-hr of accelerometry data, respectively. Unadjusted mean (SD) registered time per 20 hr period were 844 (98) min and 839 (55) min for rural and urban participants, respectively. The data reduction programme we used calculates registered time for each hr of a 24-hr period, where counts > 0 and excluding ≥ 60 min of zero runs. Valid data for 1-4 days and 5-7 days were collected from 53 and 226 participants, respectively (Table 5.1).

Table 5.1. Sample response rate by residence for number of valid days wearing.

Valid days	Rural (n = 263)		Urban (n = 16)		All (n = 279)	
	N	Counts.day ⁻¹	N	Counts.day ⁻¹	N*	Counts.day ⁻¹
1 day	8	408664 (170778)	0	-	8 (2.9)	408664 (170778)
2 days	7	368903 (109376)	1	308874	8 (2.9)	361399 (103463)
3 days	10	331367 (97764)	0	-	10 (3.6)	331367 (97764)
4 days	20	353893 (102329)	7	348372 (126794)	27 (9.7)	352462 (106622)
5 days	38	436822 (136569)	2	324523 (35692)	40 (14.3)	431207 (135431)
6 days	127	404823 (119691)	5	276559 (98803)	132 (47.3)	399964 (121167)
7 days	53	440644 (112371)	1	346588	54 (19.4)	438903 (112039)

data are unadjusted and reported as mean (SD) for all continuous variables except * categorical variables n (%)

There were no significant differences across days of valid data for TC ($p > 0.05$, n=279) (Table 5.1). Those with less than five days of valid monitoring recorded significantly lower mean registered time (778 min vs. 859 min, $p < 0.0001$), fewer mean TC (358 314 counts.day⁻¹ vs. 414 797 counts.day⁻¹, $p = 0.0025$), greater mean SED activity (822 min vs. 775 min, $p = 0.0002$) and lower mean MOD1 activity (124 min vs. 159 min, $p < 0.0001$) than those who had 5-7 valid days of monitoring. Moreover, even after adjusting for age and BMI these differences persisted

($p < 0.002$). Accelerometry data for nine rural participants were invalid due to non-compliance and accelerometer failure. Participant characteristics are reported in Table 5.2.

Table 5.2. Descriptive characteristics for rural and urban women.

Continuous variables	Residence		P^{\dagger}
	Rural (n = 263)	Urban (n = 16)	
Age (yr)	35.1 (10.5)	30.1 (7.2)	0.0168
Body-mass-index (kg.m^{-2})	26.8 (6.0)	28.5 (6.0)	0.2849
Categorical variables *			
Body mass index classification			
Normal weight ($<25 \text{ kg.m}^{-2}$)	46.4 (122)	31.3 (5)	0.3565
Overweight ($25\text{--}29.9 \text{ kg.m}^{-2}$)	22.8 (60)	37.5 (6)	0.2987
Obese ($\geq 30 \text{ kg.m}^{-2}$)	30.8 (81)	31.3 (5)	0.8097
Completion of secondary school (\geq Grade 12)	27.4 (72)	100 (16)	<0.0001
Ownership of motor vehicle (Yes)	18.3 (48)	50.0 (8)	0.0058
Electricity available inside house (Yes)	86.3 (227)	87.5 (14)	0.8100
Water collected outside dwelling (Yes)	99.6 (262)	31.2 (5)	<0.0001

data are unadjusted and reported as mean (SD) for all continuous variables except * categorical variables % (n), $\dagger p$ values evaluate rural vs. urban differences

Rural participants were significantly less sedentary ($p = 0.0042$) than urban participants, and accumulated significantly more counts in the MOD1 and MOD1VGbt bands than urban participants ($p < 0.02$) (Table 5.3).

Table 5.3. Average day accelerometry data for rural and urban women (20 hours, 04H00 – 24H00).

Raw counts and derived volumes	Residence		Difference	P^*
	Rural (n = 263)	Urban (n = 16)		
Activity counts (counts)				
Total counts (counts.day^{-1})	408 679 \pm 14 320	328 279 \pm 58 593	+80 399	0.0096
Average counts ($\text{counts.min}^{-1}.\text{day}^{-1}$)	488 \pm 18	390 \pm 72	+98	0.0103
Duration (min.day^{-1})				
SED ($\leq 99 \text{ counts.min}^{-1}$)	780 \pm 10 (65.0 \pm 0.8)	842 \pm 40 (70.5 \pm 2.3)	-61	0.0042
ACT ($\geq 100 \text{ counts.min}^{-1}$)	420 \pm 10 (35.0 \pm 0.8)	358 \pm 40 (29.5 \pm 2.3)	+61	0.0042
LGT (100–759 counts.min^{-1})	217 \pm 6 (18.1 \pm 0.5)	222 \pm 23 (18.7 \pm 1.7)	-5	0.6576
MOD1 (760–1951 counts.min^{-1})	156 \pm 6 (13.0 \pm 0.5)	91 \pm 25 (7.2 \pm 0.9)	+65	<0.0001
MOD2VG ($\geq 1952 \text{ counts.min}^{-1}$)	47 \pm 3 (3.9 \pm 0.3)	45 \pm 13 (3.6 \pm 1.1)	+2	0.7677
MOD1VG (bouts $\geq 10 \text{ min}$, $\geq 760 \text{ counts.min}^{-1}$)	53 \pm 4	33 \pm 15	+19	0.0179
MOD2VG (bouts $\geq 10 \text{ min}$, $\geq 1952 \text{ counts.min}^{-1}$)	9 \pm 1	12 \pm 5	-3	0.2788

data are reported as mean \pm 95%CI adjusted for age and BMI, values in parenthesis are the percentages of the total of 20 hours, SED = sedentary, ACT = active, LGT = light, MOD = moderate, VG = vigorous, * p -values evaluate rural vs. urban differences

Rural participants accumulated 13 490 (13 076 to 13 904) steps.day^{-1} . The majority (93.0%) of hourly step totals were accumulated at $<3000 \text{ steps.hr}^{-1}$, with 88.4% accumulated at $<2000 \text{ steps.hr}^{-1}$. The incidence rates for bouts $<3000 \text{ steps.hr}^{-1}$ and bouts $\geq 3000 \text{ steps.hr}^{-1}$ were 23.5 (20.6 to 26.4) bouts per 24 person-hr and 0.50 (0.41 to 0.59) bouts per 24 person-hr, respectively. Within the $<3000 \text{ steps.hr}^{-1}$

category, the incidence rates for 0-999 steps.hr⁻¹, 1000-1999 steps.hr⁻¹ and 2000-2999 steps.hr⁻¹ were 17.4 (15.2 to 19.6), 4.9 (4.3 to 5.6) and 1.2 (1.0 to 1.4) bouts per 24 person-hr, respectively.

Hourly PA volume patterns were relatively similar across residence (Figure 5.1). Of note the lower sedentary time (08H00 - 13H00) and higher MOD1 time (07H00 - 19H00) in the rural sample, reflecting the greater subsistence activities which rural women engage in during these time periods (collecting of wood and water, cooking, cleaning). Daily PA volumes patterns were relatively constant across week- and weekend days (Figure 5.2). SED tended to be lower in rural participants but only significantly so for Monday ($p=0.0031$). MOD1 time was higher in rural participants compared with urban participants for Monday to Friday ($p<0.03$).

Compared with urban females, rural females accumulate 385 more counts for every min of MOD1 activity (Table 5.4). However, compared with rural females, urban females accumulated 398 more counts for every min of MOD2VG. Variance inflation factors were less than 2 suggesting no or little collinearity between dependent variables. Rural women had a non-significant 16% greater odds of achieving a ≥ 10 min bout of MOD1VG activity than urban women ($p=0.189$) while urban women had a 103% greater odds of achieving a ≥ 10 min bout of MOD2VG activity than rural women ($p=0.004$) (Figure 5.3).

The estimated adherence to PA recommendations was up to 1.2 times higher in rural women for both MOD1VG and MOD2VG activity levels (Table 5.5). For MOD1VGbt activity estimated adherence was 1.4 times higher in rural females compared with urban females. In contrast, for MOD2VGbt activity, although lower than for MOD1VGbt estimated adherence, was 3.3 times higher in urban females compared with rural females.

5.4. DISCUSSION

The principal findings of this novel analysis were first that rural women accumulate greater amounts of PA than urban women within a particular count band (760-1951 counts.min⁻¹) which reflects the different types of residence-specific PA behaviours

these women exhibit. Second, depending on which moderate cutpoint was used to estimate PA public health adherence, rural women could be classified as less physically active than urban women. These results corroborate work we have reported elsewhere^{128,130,132} and adds insight into the patterns and volumes of PA in rural and urban African women.

Table 5.4. Multiple linear regression models for total accelerometry counts in rural and urban women.

Model	Goodness of fit		Outcome	Factors	Model parameter	Significance	Correlations	Collinearity
	adjusted R ²	p			β coefficient (95%CI)	p	Part	VIF
Rural (n = 263)	0.9904	<0.0001	Total counts	Age	-168 (-308 to -28)	0.0192	-0.0143	1.0263
				LGT	370 (338 to 403)	<0.0001	0.1371	1.2069
				MOD1	1149 (1117 to 1180)	<0.0001	0.4390	1.2866
				MOD2VG	3193 (3128 to 3257)	<0.0001	0.5902	1.4117
Urban (n = 16)	0.9861	<0.0001	Total counts	LGT	296 (74 to 518)	0.0131	0.0887	1.9255
				MOD1	764 (358 to 1170)	0.0015	0.1250	1.7131
				MOD2VG	3591 (3303 to 3878)	<0.0001	0.8304	1.4010

Age = yr, LGT = 100-759 counts.min⁻¹, MOD1 = 760-1951 counts.min⁻¹, MOD2VG: ≥ 1952 counts.min⁻¹, VIF = variance inflation factor

Table 5.5. Estimated prevalence of adherence (%) for two moderate-to-vigorous physical activity intensity thresholds (≥ 30 min.day⁻¹ for 5 days).

	Rural (n=263)	Urban (n=16)
Moderate-to-vigorous ≥ 760 counts.min⁻¹		
≥ 1 min	86.3	84.5
≥ 10 min bouts	38.2	27.5
Moderate-to-vigorous ≥ 1952 counts.min⁻¹		
≥ 1 min	34.4	29.0
≥ 10 min bouts	2.2	7.3

prevalence estimates for individuals with one or more valid days of accelerometer data.

Recently we have reported that rural African women accumulate in excess of 10 000 steps.day⁻¹ and have argued that this elevated ambulatory level,¹²⁷ in comparison with findings from more industrialized settings,⁶²³ is the result of greater involvement in subsistence or lifestyle activities such as housework, yard work and walking for transport. Indeed, rural women from households where wood is used for cooking, water is collected outside of the dwelling, no electricity is supplied into the dwelling and there is no access to a motor vehicle within the home, are more likely to have significantly higher fitness levels, lower adiposity, lower fasting blood glucose concentrations and increased levels of objectively measured PA ($p < 0.04$).¹²⁸

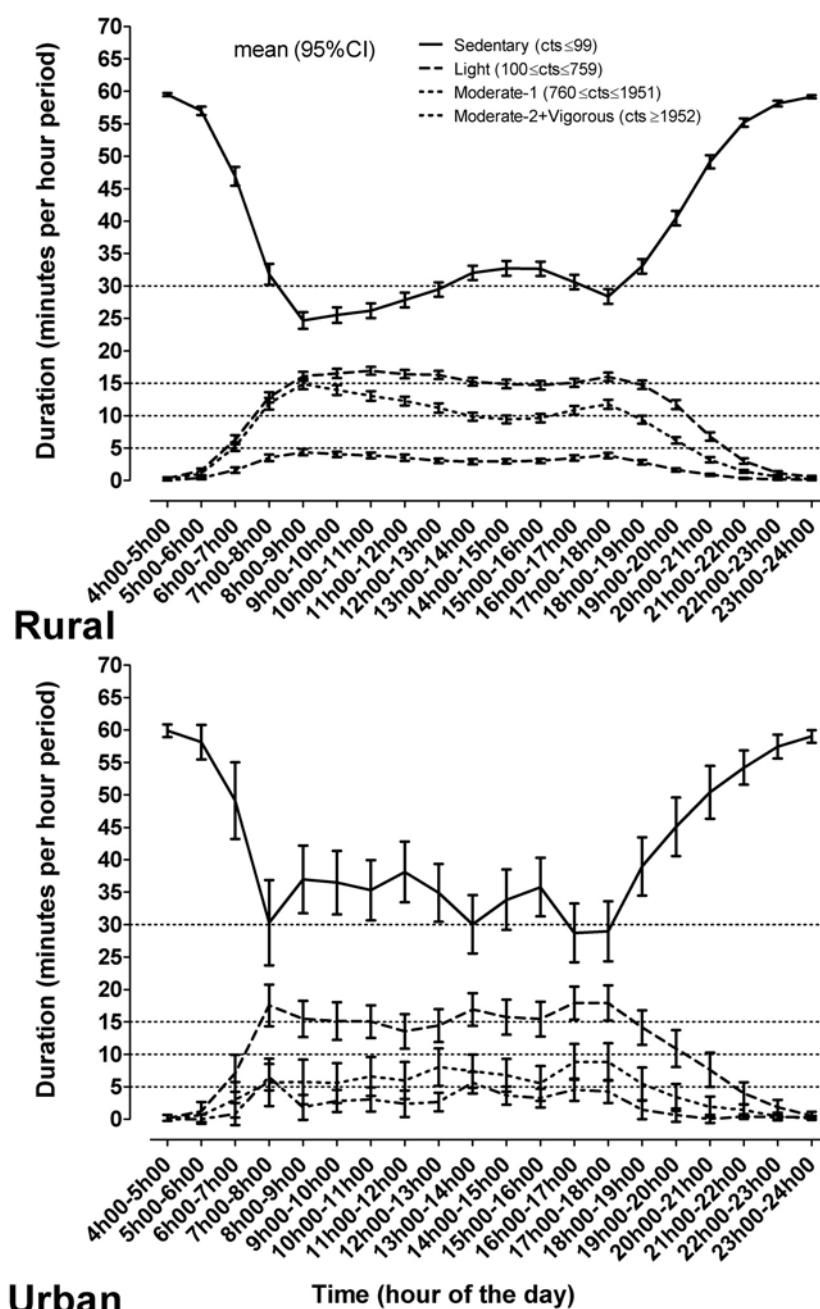


Figure 5.1. Hourly profiles by activity category for rural and urban women. Adjusted for age and body-mass-index.

Furthermore, rural women from households where there is access to a motor vehicle have a 4% higher percentage body fat adjusting for age, completion of secondary school, comorbidities and tobacco products usage ($p=0.018$).¹³²

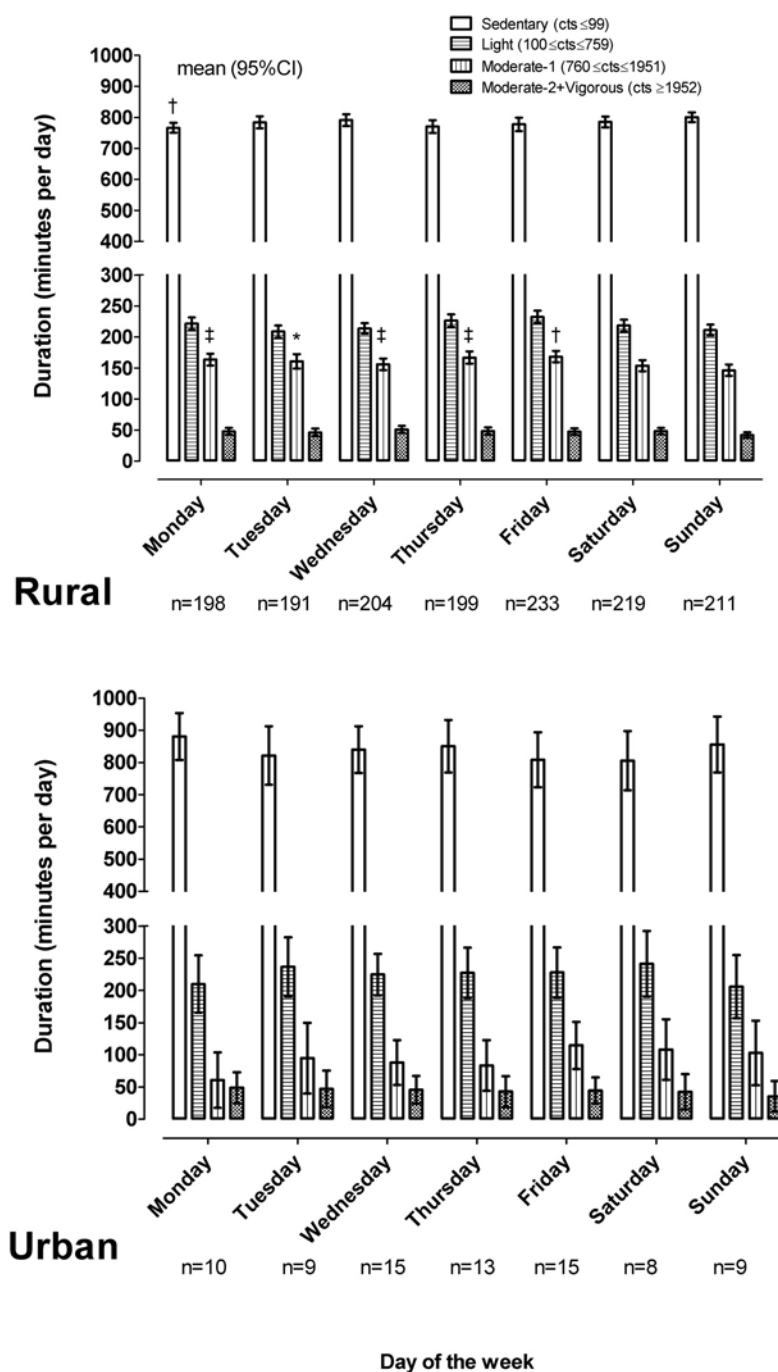


Figure 5.2. Daily activity profiles by activity category for rural and urban women. Adjusted for age and body-mass-index; p -values evaluate rural vs. urban differences, * $p < 0.05$, † $p < 0.01$, ‡ $p < 0.0001$.

In South Africa 70-74% of women are the usual household fuel (wood) and water collectors.¹¹⁸ Depending on the distance from the household to the source, people spend on average 44-71 min.day⁻¹ and 78-128 min.day⁻¹ collecting fuel and water, respectively. The time spent on housework, including fuel and water collection, ranges from 187 to 224 min.day⁻¹ for women 20-yr and older. The amount of time

spent by women on housework is on average 40 min.day⁻¹ higher for households with no appliances (fridge, electric stove, vacuum cleaner, washing machine) compared with households having four appliances.¹¹⁸ As we have argued elsewhere, these subsistence activities are light-to-moderate in intensity and are performed throughout the day^{127,128} but are probably not accurately probed by current self-report measures such that sedentarism is over-reported and physically active behaviours under-reported.¹³⁰

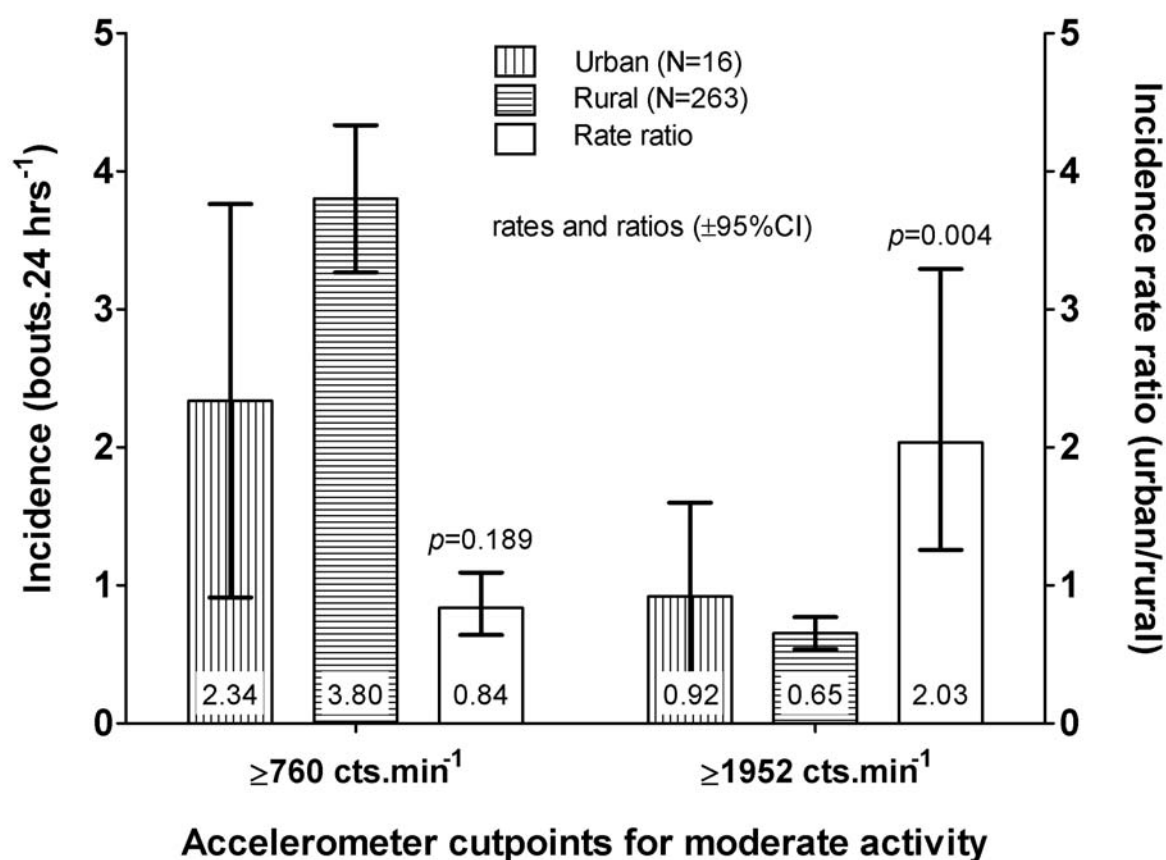


Figure 5.3. Incidence rates and rate ratios for bouts of activity (≥ 10 min) at two moderate intensity thresholds for rural and urban women. Incidence rate ratios adjusted for age, body-mass-index and total counts.

The relatively high ambulation of 13 490 steps.day⁻¹ for rural women was accumulated principally within bouts of <3000 steps.hr⁻¹. We also found that the incidence of bouts <3000 steps.hr⁻¹ was 47-fold greater than the incidence for bouts of ≥ 3000 steps.hr⁻¹. It has been suggested that accumulating 3000 steps in 30 min, 5 days.wk⁻¹, would approximate meeting current PA guidelines of 150 min.wk⁻¹ of

moderate intensity activity.³⁸³ It is likely then that rural women are accumulating high step volumes not by participation in bouts of exercise or recreational activities, but rather through light-to-moderate intensity ambulatory activity throughout the day. Compared with data collected in similarly aged females from the same population with the NL-2000 accelerometer-based pedometer¹²⁷ the daily step count reported here is marginally elevated (1763 steps.day⁻¹) because of the greater sensitivity of the MTI Actigraph.⁶¹⁶ Further analysis is required on the current data set to investigate the intensity of the steps taken using accelerometer intensity thresholds⁶²³ and also the effect of censoring the number of steps taken using sedentary intensity thresholds.^{389,623}

This study has provided more direct evidence that the increased PA levels seen in rural African women is the result of movement accumulation which falls within a narrow band of 760-1951 counts.min⁻¹. Matthews has summarized convincing evidence for a moderate threshold of 760 counts.min⁻¹,³⁸⁸ such that many of the subsistence or lifestyle activities performed by both rural and urban women would be assessed within the range of 760-1951 counts.min⁻¹. Using a moderate cutpoint of 760 counts.min⁻¹, Matthews *et al.* found a prevalence of 30% for meeting PA public health recommendations (moderate intensity for 5 days.wk⁻¹, 30 min.day⁻¹) in 88 urban participants who accumulated on average 308 counts.min⁻¹.day⁻¹.³⁸⁹ These results are similar to the estimated 27.5% adherence for urban woman accumulating 390 counts.min⁻¹.day⁻¹ reported in this study. Recent field validation of the 760 counts.min⁻¹ cutpoint in comparison with output from the multi-sensor IDEEA monitor found the least error and highest correlation for moderate intensity PA estimates.⁶⁶⁵

Our results also highlight the fact that although accelerometers are a preferred method for measuring free-living PA where feasible, the uncritical application of intensity thresholds can have as significant a misclassification effect as self-report measures. Pate *et al.* emphasize the importance of analyzing accelerometry counts across the full range of energy expenditure rates below moderate intensity.⁴⁷² Ignoring accelerometer counts which contribute to light-to-moderate energy expenditure over extended periods of time, and concentrating solely on moderate-to-vigorous intensity thresholds which exclusively probe bouts of activity to fulfil current

PA guidelines can result in the misclassification of an otherwise active individual as sedentary.⁴⁷² Our results have demonstrated that by ignoring the contribution of counts below the oft-used moderate-to-vigorous cutpoint of 1952 counts.min⁻¹, can result in classifying rural women as inactive, despite accumulating over 10 000 steps.day⁻¹ and more than 400 000 counts.day⁻¹.

To the best of our knowledge, this is the first South African study that has used an objective measure of PA to compare the pattern of uni-axial accelerometer measured PA counts across a number of count bands between rural and urban black South African women from communities at various stages of the epidemiological transition. Moreover, this study is one of the few studies that have investigated PA in African communities using objective measures of PA such as accelerometry,^{29,58,128,168} combined heart rate and accelerometry,¹¹⁹ pedometry^{127,132} and doubly labelled water.^{29,371} Our urban estimates for SED+LGT and MOD1VG of 89.2% and 10.8%, respectively are in close agreement to values obtained for 20 urban females resident in an informal settlement in South Africa (88% and 11.3%).¹⁶⁸ Average daily TC, LGT+MOD1 time and MOD2VG time in 17 male and female rural Cameroonians was estimated at 391 400 counts.day⁻¹, 340.6 min.day⁻¹ and 53.5 min.day⁻¹, respectively compared with our rural estimates of 408 679 counts.day⁻¹, 373 min.day⁻¹ and 47 min.day⁻¹.²⁹ Similarly the estimates for 16 urban Cameroonians are generally comparable to our results (total counts: 397 300 counts.day⁻¹ vs. 328 279 counts.day⁻¹, LGT+MOD1: 293.2 min.day⁻¹ vs. 313 min.day⁻¹, MOD2VG: 61.7 min.day⁻¹ vs. 45min.day⁻¹).²⁹ Nationally representative estimates for average counts in 936 women 20-59 yr from a highly urbanized setting ranged from 308.2 to 343.3 counts.min⁻¹.day⁻¹, which are lower than our rural and urban estimates (390 to 488 counts.min⁻¹.day⁻¹).⁶⁰⁶ Moderate-to-vigorous activity accumulated in ≥10 min bouts are similar to our results (6.1 to 6.8 min.day⁻¹ vs. 9 to 12 min.day⁻¹), but for accumulated PA ≥1 min our rural and urban estimates are more than 2-fold higher. Our estimates for the prevalence of sufficient PA (bouts ≥10 min, moderate-to-vigorous PA, 30 min, 5 times.wk⁻¹) was 2.3% to 6.6% which is in close agreement with the 3.2% for reported by Troiano *et al.*⁶⁰⁶ The TC achieved by our rural and urban samples are similar to values reported for 18-39 yr-old Hispanic males (411 700 counts.day⁻¹) and 40-59 yr old Hispanic females (286 700 counts.day⁻¹).²⁵⁹

Taken together, these results suggest that our urban sample is comparable to the most active segments of a highly urbanized female population and to urban African samples. However, our rural sample achieved activity counts and volumes in agreement with rural African populations, and were similar to the most active male segments of a highly urbanized population. As such, our results would appear to be valid for both the rural and urban samples.

Current estimates for the number of days an accelerometer needs to be worn to provide a valid and reliable estimate of habitual, free-living physical activity, is at least 3 days.^{37,135} Our present results show relatively stable PA patterns and volumes across days. Consequently, we decided to implement the methodology recently reported for the NHANES study⁶²³ wherein it is suggested that fewer days of accelerometer wear may be a proxy measure for sedentary behaviour and since sedentary individuals are likely to perform little activity when the monitor is not worn, the margin of error will be low. Indeed, as with the NHANES accelerometry data⁶²³ we have also shown a bias in that those with <5 days of valid accelerometry data record less PA than those with 5-7 days of valid accelerometry data. However, excluding this data would have inflated the unadjusted rural-urban total count difference by 33016 counts.day⁻¹ or 8 min of active time per day (≥ 100 counts.min⁻¹).

Several limitations must be acknowledged. First, because of convenience sampling prevalence estimates were calculated for comparative purposes only. Second, a period of 3-4 yr separates the two datasets. There has been no large-scale, sustained PA public health campaign or any major recreational facility development projects in the rural or urban areas where participants were recruited. It is unlikely that the urban sample would have substantively increased PA over the 3-4 yr. However, the rural sample would likely have been more physically active in 2000 because of increased electrification in the area since 2000.¹²⁸ Consequently, if both samples were measured in 2000 the group differences in PA levels would likely have been even larger. Third, the urban sample was small suggesting caution as to the generalizability of the results to urban black South African women. However, the results we obtained were significant and in the expected direction, of sufficient practical magnitude such that the sample size provided enough power to detect the

current rural/urban differences and agreed with findings from other urban African settings. As the PA patterns and choices change in the rural sample because of the Physical Activity Transition ³⁰⁶ the rural/urban differences will become smaller and larger sample sizes would be required in future to detect these differences. Finally, there is a lack of objectively measured PA data from African contexts, and in particular sub-Saharan Africa such that our results add substantively to the growing body of knowledge for objectively-measured PA in rural Africa.

In conclusion, this analysis suggests that the use of appropriate accelerometer intensity thresholds will provide unique insights into PA patterns, especially when comparing communities that might differ in terms of PA modes and also as PA choices change as the Physical Activity Transition progresses.

CHAPTER 6: RELATIONSHIP BETWEEN ADIPOSITY AND PEDOMETER-ASSESSED AMBULATORY ACTIVITY IN ADULT, RURAL AFRICAN WOMEN

Data in this chapter has been published in the International Journal of Obesity 32: 1327-1330, 2008.

University of Cape Town

6.1. INTRODUCTION

Few studies in South Africa have investigated obesity in relation to PA in rural African populations and have relied on questionnaires to estimate PA.³²⁴ To the best of our knowledge there is only one South African study that has used objectively-measured PA (heart rate monitoring) to investigate the relationship with measures of adiposity and resting blood pressure in an elderly Mixed-Ancestry sample.³³¹ There are no pedometry data from uniquely South African populations, specifically rural, adult, black women. Therefore, the objectives of this study were firstly to investigate the association between measures of adiposity and pedometry-assessed ambulatory PA. Secondly to explore the level of protection ambulation offers against obesity, and the effect factors such as motor vehicle access could have on obesity risk in this rural African community.

6.2. METHODS

A random list of 600 potential subjects (female, 15-55 yr, permanent residents, non-pregnant) was generated from the DHDSS relational database.¹⁵ If the potential subject was not at home or refused to participate, the field workers moved onto the next subject in the random list. Due to financial constraints, a total of 151 eligible subjects were recruited. All interviews, anthropometric measures and accelerometer placement were conducted by trained black male and female field workers. The first author was responsible for securing funding, field worker training, the pedometer data management and overall data entry, data analysis and data reporting. Signed informed consent was obtained from all participants. The study was approved by the Ethics Committee of the University of the North.

Anthropometric measures of stature, body mass, WC, and SSKF (triceps, biceps, subscapular, supra-iliac) were performed according to standardised procedures.²⁷² Body mass index (BMI) and percentage body fat (PBF) were calculated.¹⁸⁰ Obesity was defined as BMI $\geq 30 \text{ kg.m}^{-2}$ or WC $\geq 88 \text{ cm}$,⁴⁴³ and $\geq 75^{\text{th}}$ percentile of PBF (37.7%). Subjects were categorized using combinations of BMI and WC cut-points.⁴⁴³ Electronic pedometers (Yamax DigiWalker SW-401, New Lifestyles Inc.,

Lee's Summit, MO, USA) were worn for 7 days.⁴⁴ Public health indices for steps.day⁻¹ were: Sedentary: <5000 steps.day⁻¹, Low-Somewhat active: 5000-9999 steps.day⁻¹, Active-Very active: ≥10 000 steps.day⁻¹.⁶¹⁸

6.2.1. Statistical Analyses

The association between continuous variables (age, adiposity, pedometer output) was explored with zero-order and partial (age-adjusted) correlation coefficients. Linear trends and Analysis of Covariance tested continuous measures across ordered obesity categories. Multiple linear regression analyses were performed with adiposity measures as dependent variables. Explanatory variables forced into the model were mean steps.day⁻¹, age, motor vehicle access, completion of secondary school, co-morbidities (self-reported diabetes and/or hypertension), and tobacco products usage. To investigate the risk of obesity in relation to pedometer-assessed ambulation, odds ratios (OR ±95%CI) were derived from logistic regression models for BMI-, WC- and PBF- defined obesity, adjusting for age, motor vehicle access, completion of secondary school, co-morbidities, and tobacco products usage. The odds at pedometer-assessed ambulation levels were compared with the odds at an arbitrary reference point (4999 steps.day⁻¹), to determine the risk of obesity:

$$OR_i = \text{Exp}[\beta \times (X_i - X_{\text{ref}})]$$

where Exp is exponent e, X_i is a specific pedometer-assessed ambulation level, X_{ref} is the reference point, and β is the coefficient of pedometer-assessed ambulation derived from logistic regression. Data were analysed using appropriate statistical software (SPSS 11.0.1.) and significance was set at $p < 0.05$.

6.3. RESULTS

Of the original 151 subjects recruited, 121 subjects (80.1%), which represents ±8% of the larger DHDSS 15-55 yr-old female population, wore the pedometer for seven days. There were no significant differences between compliers and non-compliers for physical or socio-demographic variables ($p > 0.3$). Due to funding and personnel constraints, readings could not be taken every day and units were collected after seven days of recording. Subjects were asked whether they wore the units properly (right side up) during waking hours for seven days. If subjects replied negatively or could not provide accurate times or days for non-compliance their data was excluded

from the subsequent analyses. Consequently, shorter time periods of three to five days of recording could not be included in the analyses. Descriptive statistics are provided in Table 6.1 for compliant subjects. The prevalence of sedentarism was three-fold less than the prevalence for active-very active (Figure 6.1). Mean steps.day^{-1} was significantly ($p<0.02$) related to BMI and WC; $r=-0.22$ and $r=-0.23$, respectively. After adjustment for age, only BMI was significantly related to ambulation (Figure 6.1).

Table 6.1. Subject physical and socio-demographic characteristics.

Socio-demographic *		
	Resident in built, formal housing unit	92.6 (112)
	Water collected outside dwelling	65.3 (79)
	Have electricity in the dwelling	83.5 (101)
	Wood used for cooking purposes	86.8 (105)
	One or more persons in household owns a motor vehicle	18.2 (22)
	Completion of secondary school (Grade 12)	28.9 (35)
Body composition		
	Age (yr)	32.9 (10.7)
	Body mass index (kg.m^{-2})	26.0 (5.9)
	Waist circumference (cm)	79.4 (11.9)
	Percentage body fat (%)	31.2 (7.4)
Prevalence of obesity *		
	Body mass index $\geq 30 \text{ kg.m}^{-2}$	24.8 (30)
	Waist circumference $\geq 88 \text{ cm}$	24.8 (30)
	Percentage body fat $\geq 37.7 \%$	26.4 (32)
Pedometry †		
	All ages (steps.day^{-1})	9085 (4014)
	<24 yr (steps.day^{-1})	10 273 (4385)
	24 and 37 yr (steps.day^{-1})	8340 (3652)
	$\geq 38 \text{ yr}$ (steps.day^{-1})	8661 (3802)

n = 121, values reported as mean (SD) except * % (n), † groups constructed from tertiles

Pedometry-assessed ambulation was significantly related to BMI, even after adjusting for a number of covariates ($\beta=-0.0002839$, $p=0.035$); for every 5000 steps.day^{-1} increase, BMI decreases by 1.4 kg.m^{-2} . Ambulation was not associated with PBF ($p=0.940$) or WC ($p=0.093$). However, access to a motor vehicle within the household was significantly related to PBF ($\beta=3.968$, $p=0.018$); easier access to a motor vehicle increased PBF by 4%. When categorizing according to disease risk (low-to-extremely high) using a combination of BMI and WC, the linear trend in increasing age ($p=0.042$) and decreasing pedometry-assessed ambulation ($p=0.02$) was significant. After adjustment for age using Analysis of Covariance, the significant negative, linear trend across disease risk categories for pedometry-assessed ambulation persisted ($p=0.036$). Pedometry-assessed ambulation was significantly

associated with BMI-defined obesity; adjusted OR=0.34 (95%CI: 0.13 to 0.89), unadjusted OR=0.32 (95%CI: 0.13 to 0.78). The OR for WC- and PBF-defined obesity were in the expected direction but did not reach statistical significance (OR=0.42 to 0.57, $p>0.1$). Compared with achieving <5000 steps.day⁻¹, the risk of BMI-defined obesity was reduced by 35% at 7500 steps.day⁻¹, 52% at 10 000 steps.day⁻¹, and 62% at 12 500 steps.day⁻¹. The reduction in risk was more pronounced at moderate levels of ambulation such that risk changed 52% from 5000- to 10 000 steps.day⁻¹, 35% from 10 000- to 15 000 steps.day⁻¹, and 26% from 15 000- to 20 000 steps.day⁻¹.

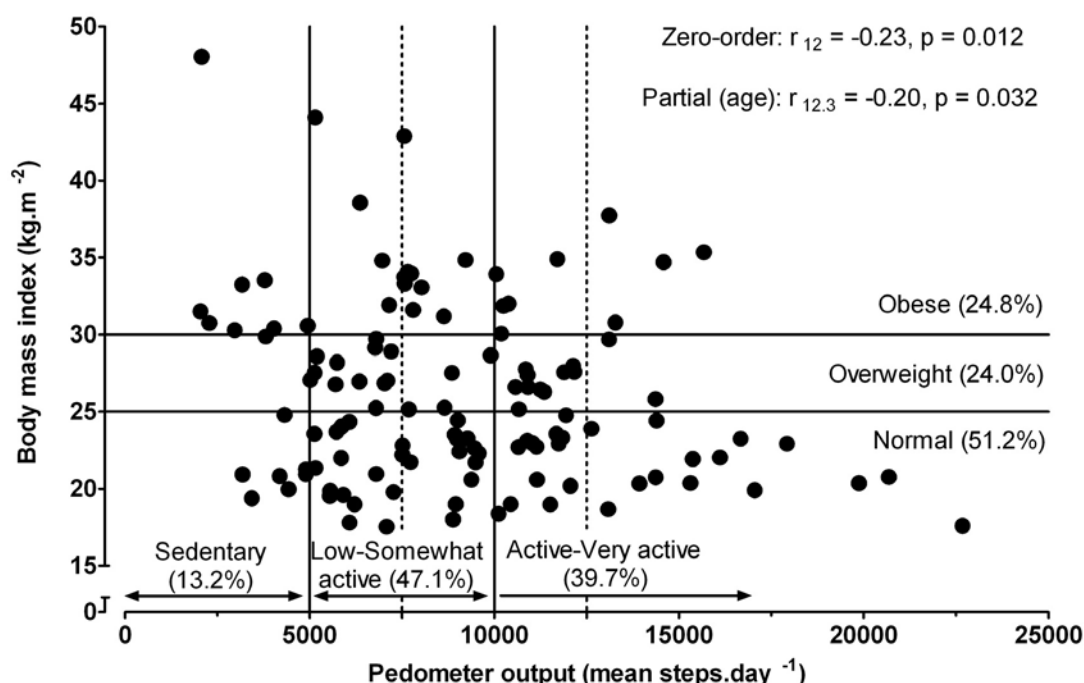


Figure 6.1. Scatter plot of body mass index and pedometer-assessed mean steps.day⁻¹. Prevalences for adiposity levels and step count cut-points are indicated in parentheses. Obese: ≥ 30 kg.m⁻², Overweight: 25-29 kg.m⁻², Normal: < 25 kg.m⁻², Sedentary: < 5000 steps.day⁻¹, Low-Somewhat active: 5000 – 9999 steps.day⁻¹, Active-Very active: $\geq 10\,000$ steps.day⁻¹

6.4. DISCUSSION

To the best of our knowledge, this is the first study that has used an objective measure of PA to investigate the association between adiposity and ambulation, in a rural black South African community undergoing epidemiological transition. Generally, South African studies have found low to moderate inverse relationships between PA and adiposity in black South African populations and ³²⁴ few studies

have used non-categorical, unit-based measures of PA.³⁶⁴ Objectively-measured PA not only provides comparable unit-based output, but also greatly reduces the impact of language and cultural influences on PA estimates, as opposed to questionnaires. Therefore, it is important that studies utilizing objectively-measured PA are conducted to verify the findings of questionnaire-based surveys.

Estimates of the prevalence of sedentarism in black South African females range from 27.3% to 85.6% using PA questionnaires^{15,323,364,570} which is substantially higher than the 13.2% found in this study. It is likely that the higher and varied prevalence of sedentarism found in questionnaire-based surveys is the result of a greater number of urban subjects and diverging PA assessment instruments that differ in terms of output (unit-less vs. unit-based) and characterisation of active and sedentary behaviour.^{15,323,364,570} In comparison with pedometry-assessed ambulation levels in industrialized settings⁶²¹ our results show a reversal of the prevalence of sedentarism and active behaviour; sedentarism: industrialized settings: 44% vs. developing country: 13.2% and active behaviour: industrialized setting: 13.9% vs. developing country: 39.7%. Our findings suggest that females in the DHDSS accumulate relatively large amounts of physical activity by participating in subsistence activities. Moreover, since few females have access to motor vehicles, much of the transport within the DHDSS is through walking. This would explain why 16.5% of the sample achieved $\geq 12500 \text{ steps.day}^{-1}$.

A number of North American studies have found significant associations between pedometer-assessed ambulation and BMI ($r=-0.27$ to $r=-0.42$), WC ($r=-0.43$ to $r=-0.62$) and PBF ($r=-0.27$ to $r=-0.71$).^{43,111,591,617,621,628} South African surveys have found significant ($p \geq 0.03$) but low to moderate associations between PA and BMI ($r=-0.14$), WC ($r=-0.15$) and sum of skinfolds ($r=-0.10$).³²⁴ We did not find the clearly inverse relationships between adiposity and ambulation that have been found in North American studies. Our findings tend to concur with results from South African questionnaire-based PA surveys that have found low to modest associations between PA and adiposity.³²⁴ The reasons for the lack of association between adiposity measures and pedometer output are unclear. It is likely that dietary factors need to be considered as well as subsistence demands. In other words, even in the

face of high adiposity levels, subsistence tasks and active travel are still required. The significantly increased adiposity in households with access to a motor vehicle in this study is in agreement with the significantly increased risk for BMI-defined obesity in females in Chinese households with motor vehicles.⁵⁷

Acknowledging that causality cannot be attributed to cross-sectional findings, we found a significant multivariate-adjusted reduction in risk of 52% against increased adiposity by accumulating 10 000 steps.day⁻¹ compared with <5000 steps.day⁻¹. A large prospective study of middle-aged women conducted in an industrialised setting found a significant multivariate risk reduction (52%, $p<0.001$) for coronary heart disease by walking ≥ 2 hr.wk⁻¹.³⁴⁵ A cross-sectional study investigating the determinants of obesity in black South African women,³²⁴ found a significant multivariate risk reduction of 62% ($p=0.001$) for obesity for those within the highest tertile of PA. This tertile of PA included walking to work at a moderate pace for 31 to 60 min.day⁻¹.³²⁴ Considering that those accumulating ≥ 10 000 steps.day⁻¹ average ~ 60 min.day⁻¹ of moderate PA,³³⁹ our multivariate risk reduction estimate for obesity appears to be valid.

Possible sources of error are firstly that the pedometers used in this study will only accurately record ambulatory activity above a specific threshold.⁴⁴ Secondly $\sim 20\%$ of the subjects did not wear the pedometer for seven days. It is possible that those not complying could have increased the group average for ambulation because of the low prevalence of motorised transport within this rural community.

In conclusion, this study reports pedometry-assessed ambulatory levels in a rural African sample and has shown significant associations with adiposity. Moreover, passive, motorised transport has also been shown to be significantly related to adiposity.

CHAPTER 7: DESCRIPTIVE EPIDEMIOLOGY OF AMBULATORY ACTIVITY IN RURAL BLACK SOUTH AFRICANS

Data in this chapter has been published in *Medicine and Science in Sports and Exercise* 42(7): 1261-1268, 2010.

7.1. INTRODUCTION

Globally, regionally and nationally physical inactivity is considered a leading risk factor for chronic diseases of lifestyle.^{198,300} Physical inactivity has been estimated to contribute 1.3% to global mortality, 22% to ischaemic heart disease burden and 7% to stroke burden.¹⁹⁸ In low- and high-mortality developing regions, physical inactivity contributes 5% and 21-22% to stroke and ischaemic heart disease burden, respectively.¹⁹⁸ Recently, the SACRACG attributed 20-30% of to ischaemic heart disease, ischaemic stroke and Type 2 diabetes mellitus to physical inactivity.³⁰⁰

The South African prevalence of physical inactivity has been estimated to be 43-49%.³⁰⁰ This estimate is based on data collected using the IPAQ¹⁴¹ during the 2003 World Health Study and provides the first nationally representative data set on physical inactivity in South Africa.²⁴⁰ However, caution has been raised²⁴⁰ regarding the low validity and reliability coefficients for the IPAQ in rural areas of developing countries.¹⁴¹

A recent large-scale, population-based survey of objectively-measured PA, in a highly urbanised, developed country, has reported discrepancies between objective and subjective measures of PA.⁶⁰⁶ The possibility of discrepancies from a South African perspective has also been raised.¹³⁰ Estimates for physical activity/inactivity using objective measures (accelerometers, pedometers) in rural, black South African women suggest higher PA volumes and lower physical inactivity prevalences, than is suggested by subjectively-measured surveys.¹³⁰ There is thus a need for objectively-measured PA surveys to be conducted, especially in rural settings, to verify the self-reported prevalences of physical activity/inactivity for rural South African populations.^{141,240} Moreover, there is a dearth of objectively-measured PA data from African settings.^{58,132,135} To date, only one objectively-measured, cross-sectional survey of seven-day PA has been reported for a South African sample.¹³² The study reported crude physical activity and inactivity prevalences of 39.7% and 13.7%, respectively and low-to-moderate associations between average daily step counts and adiposity measures for a sample of rural, black women.¹³² However, the sample

size was small, limited to adult females, and the spring-levered pedometer used could not store daily step counts for later retrieval.¹³²

Therefore, the primary objective of this study was to investigate the distribution of pedometry-assessed ambulation in a larger, more representative sample of a rural black South African population, particularly with regard to some objectively-measured public health indices, using an accurate and robust accelerometer-based pedometer with a seven-day memory capacity. The secondary objective was to investigate the relationship between pedometry-assessed ambulatory activity and measures of adiposity.

7.2. METHODS

7.2.1. Field Site

The DHDSS was established in 1995 and a yearly census has been conducted since 1996 with trained, local enumerators visiting households. The DHDSS consists of a relatively stable population of around 8000 residents. Inhabitants of this area are northern Sotho-speaking people, belonging to the Pedi group.^{13-15,131} The DHDSS is situated in the Limpopo Province which constitutes 10.2% and 11.8% of the total land area and total population of South Africa, respectively.⁵⁶³ Nearly 90% of the Limpopo population live in non-urban areas, and 97.2% of the population are black Africans. Nationally, 42.8% live in non-urban areas and 79% are black South Africans. The Limpopo provincial age-sex profile of the black African population yields a pattern typical for a developing population; triangular with a large base and concave sides. In addition the contribution of the 0-4 yr old age group for both sexes is contracted.⁵⁶³ The DHDSS has a population pyramid and age structure nearly identical to that of the Limpopo Province.^{131,563} Moreover, the prevalence of socio-economic, infrastructural and education variables show similar trends in the DHDSS (see results section) compared with provincial estimates.⁵⁶³ These data suggest that the DHDSS is representative of the Limpopo Province, specifically with regard to the black, non-urban population.

7.2.2. Sample size

Using data from a previous cross sectional study,¹³² and assuming small effect sizes (Cohen's conventions) for correlations, independent t-tests, contingency tables, one-way analysis of variance, multiple linear regression and binary logistic regression, sample size estimations ranged from 485 to 1096 (median: 792) for $\alpha = 0.05$ and $1 - \beta = 80\%$.²⁰³

7.2.3. Subjects

Subjects were conveniently recruited ($n = 830$) from households in the DHDSS between December 2005 and December 2007. Prior to the commencement of the survey, local community chiefs were visited to explain the purpose of the study, request permission to recruit subjects from the communities and to have the leaders inform the communities about the survey. A random sample of 1000 subjects was generated from the DHDSS relational database and distributed to trained fieldworkers. However, fieldworkers reported difficulty in contacting the subjects during house-to-house visits. Direct contact was necessary because provincial estimates for telephone access are 20.2% for cellular telephone only and 3.1% for landline telephone only within the dwelling.⁵⁶³ Because of time and financial constraints it was decided that fieldworkers would recruit subjects house-to-house, at common meeting places and through general mouth-to-mouth promotion of the survey. Signed informed consent was obtained from all participants. The study was approved by the Ethics Committee of the University of Limpopo (Turfloop Campus).

7.2.4. Study protocol

The participants were contacted twice over a nine day period. On the first occasion, subjects were recruited and completed the informed consent, relevant sections of a health questionnaire and provided anthropometric data. Anthropometric measurements and interviews were performed by trained, black local fieldworkers. Finally, subjects were instructed on the required procedures for wearing the pedometer. Nine days later the pedometers were collected and the data recorded by the field workers for later data entry by a trained data capturing clerk. The first author assisted in field worker training and securing funding, and was responsible for

construction of a relational database, data management, data analysis and data reporting. Subjects received a small honorarium on completion of the study.

7.2.5. Anthropometric measurements

Standard anthropometric measures of stature (nearest 1 cm), body mass (nearest 1 kg) and WC (midway between lower rib margin and iliac crest, steel anthropometric tape, nearest 1 cm) were obtained. Obesity was defined as BMI $\geq 30 \text{ kg.m}^{-2}$ or WC $\geq 88 \text{ cm}$ (females), WC $\geq 102 \text{ cm}$ (males).⁵⁰⁹ We also categorized subjects using BMI categories (underweight: $< 18.5 \text{ kg.m}^{-2}$, normal weight: $18.5\text{-}24.9 \text{ kg.m}^{-2}$, overweight: $25\text{-}29.9 \text{ kg.m}^{-2}$, obese: $\geq 30 \text{ kg.m}^{-2}$).⁴⁴³

7.2.6. Physical activity volume

To objectively quantify PA volume of the subjects, piezo-electric pedometers (NL-2000, New Lifestyles Inc., Kansas City, MO, USA), not affected by pedometer tilt (up to approximately 15 degrees) or adiposity level,¹⁴⁶ were worn for nine consecutive days, so that when the pedometers were collected seven complete days step totals were stored and recalled.⁵³⁷ Data for day 1 and day 9 were omitted because these were incomplete days. The pedometer was worn on the right waist, securely attached to a nylon belt and sealed with surgical tape. The pedometers could be removed for sleeping and bathing purposes by unclipping the nylon belt. Ambulation PA volume was defined as the average steps.day⁻¹ (total steps recorded / days pedometer worn). Average steps.day⁻¹ was calculated for a seven-day period (Weekly: Monday-Sunday), a five-day period (Weekday: Monday-Friday) and a two-day period (Weekend: Saturday-Sunday). Public health indices (thresholds) for steps.day⁻¹ were defined as follows: Sedentary: $< 5000 \text{ steps.day}^{-1}$, Low active: $5000\text{-}7499 \text{ steps.day}^{-1}$, Somewhat active: $7500\text{-}9999 \text{ steps.day}^{-1}$, Active: $\geq 10\,000 \text{ steps.day}^{-1}$, and Very active: $\geq 12\,500 \text{ steps.day}^{-1}$.⁶¹⁸ Subjects were also described as complying with public health pedometry guidelines ($\geq 10\,000 \text{ steps.day}^{-1}$) or not ($< 10\,000 \text{ steps.day}^{-1}$) for each day. A summary variable was created indicating the number of days a subject was compliant (0-7 days) and from this continuous variable a categorical compliance variable was also created (0-1 days, 2-3 days, 4-5 days, 6-7 days).

7.2.7. Statistical analysis

Data was expressed as mean (SD), mean (95%CI) or % (n). Crude prevalences for pedometry thresholds were age-standardized according to the world population.⁷ Where necessary, skewed data were transformed (natural logarithms). Independent t-tests and one-way analysis of variance with *post hoc* multiple comparison analyses (Sidak's t-test) assessed group differences. To examine the ordered association between public health pedometry thresholds and categorical variables, Pearson's Chi-square analyses were conducted. We performed multiple linear regression analyses with BMI and WC, as dependent variables and reported the association between continuous variables with zero-order and partial correlation coefficients. Explanatory variables that were forced into the model were pedometry output, age, sex, village, and season. The mean number of days that complied with $\geq 10\,000$ steps, adjusted for age and BMI, was calculated using a univariate general linear model. Repeated measures general linear models were used to determine steps.day⁻¹ across days, adjusting for age and BMI. Models were created for seven days, five week days and two weekend days. *Post hoc* multiple comparison analyses (Sidak's t-test) assessed group differences. To investigate the risk of obesity in relation to pedometry-assessed ambulation, odds ratios (OR \pm 95%CI) were derived from logistic regression models for BMI- and WC-defined obesity adjusting for sex, age quartile, village and season. Data were analysed using appropriate statistical software (SPSS Inc. SPSS Statistical Software: Release 14.0. SPSS Corp; Chicago, IL, 2005). Significance for all inferential statistics was set at $p < 0.05$.

7.3. RESULTS

Of the 830 subjects on the main database, 792 had pedometry data. One subject was missing anthropometry data and the pedometry data for two male subjects were excluded as outliers (36.4 yr: 52 010 steps.day⁻¹, 45.2 yr: 53 418 steps.day⁻¹). A complete dataset for anthropometric, demographic and pedometry data was provided by 789 subjects. Because <100 subjects per village were recruited from three villages (Ga Tjale, Moduane, Ntsima) statistics are reported for these villages combined (n = 122). Moreover, because these villages are geographically closely linked, grouping these villages was valid. Unpublished results from a 2006 survey conducted in the DHDSS found that although the majority of subjects reported living

in formal, bricked housing (96.0%) and had electricity supply in the house (72.2%), only 8.4% reported a tap inside the house, almost 80% still used wood for cooking, and 20.3% reported access to a motor vehicle within the household. Completion of secondary school (Grade 12) was attained by 15.9% of the subjects. Subjects reported perceived overall health rating as good-to-very good (81.2%).

Descriptive statistics for anthropometric, demographic and pedometry variables are reported in Table 7.1 as unadjusted means and prevalences.

Table 7.1. Unadjusted sex-specific descriptive statistics for anthropometric, pedometry and demographic variables.

Descriptive variables	Male (n = 273)	Female (n = 516)	All (n = 789)
Age (yrs)	28.4 (17.6)	40.5 (20.9)	36.3 (20.7)
Age distribution (quartiles) *			
13.7 – 18.4 yrs	38.1 (104)	18.0 (93)	25.0 (197)
18.5 – 28.8 yrs	31.5 (86)	21.7 (112) ¶	25.1 (198)
28.9 – 51.2 yrs	18.3 (50)	28.5 (147) ¶	25.0 (197)
51.3 – 95.7 yrs	12.1 (33)	31.8 (164)	25.0 (197)
Body mass (kg)	59.4 (12.0)	66.5 (16.3)	64.1 (15.3)
Stature (cm)	167.2 (9.2)	158.5 (7.9)	161.5 (9.3)
Body-mass-index (kg.m ⁻²)	21.2 (4.0)	26.5 (6.4)	24.7 (6.2)
Body-mass-index category *			
< 18.5 kg.m ⁻²	26.4 (72)	5.2 (27)	12.5 (99)
18.5 – 24.9 kg.m ⁻²	60.8 (166)	42.6 (220)	48.9 (386)
25.0 – 29.9 kg.m ⁻²	8.4 (23)	25.0 (129)	19.3 (152)
≥ 30 kg.m ⁻² ‡	4.4 (12)	27.1 (140)	19.3 (152)
Waist circumference (cm)	72.6 (10.9)	84.0 (14.9)	80.1 (14.7)
Waist circumference category *			
males: ≥102 cm, females: ≥88 cm ‡	1.1 (3)	37.6 (194)	25.0 (197)
Ambulation (7-day average, steps.day ⁻¹)	14 130 (5536)	11 068 (4628) ¶	12 127 (5167)
Ambulation distribution (quartiles) †			
≤8754 steps.day ⁻¹	6217 (2479) 37	5837 (2190) 160	5908 (2245) 197
8755 – 11 890 steps.day ⁻¹	10 405 (954) 67	10 382 (890) 130	10 390 (910) 197
11 891 – 15 082 steps.day ⁻¹	13 359 (937) 65	13 209 (878) 133	13 258 (898) 198
≥15 082 steps.day ⁻¹	19 826 (3605) 104	17 964 (2533) 93	18 947 (3273) 197
Village *			
Madiga	34.8 (95)	33.9 (175)	34.2 (270)
Sephateng	31.1 (85)	20.3 (105) ¶	24.1 (190)
Manthedeng	17.9 (49)	30.6 (158) **	26.2 (207)
Combined §	16.1 (44)	15.1 (78)	15.5 (122)

values reported as mean (SD) and * % (N), † mean (SD) N; ‡ obesity defined as body-mass-index ≥30 kg.m⁻² and waist circumference, males: ≥102 cm, females: ≥88 cm; § Combined: Ga Tjale – Moduane – Ntsima; significant differences male vs. female: || $p < 0.0001$, ¶ $p < 0.01$, ** $p < 0.001$

Between-subject effects for adjusted average ambulatory activity (full week) are reported in Table 7.2. The only adjusted mean, significantly less than 10 000 steps, was that for females in Manthedeng village (9084 steps.day⁻¹ 95%CI: 8309 to 9859).

Ambulation levels were significantly lower in females compared with males for the two-, five- and seven-day periods; differences = -1483 steps, -1154 steps and -1248 steps, respectively ($p < 0.01$). Overall, ambulation levels were significantly lower in the oldest age quartile (difference = -2956 to -3789 steps, $p < 0.0001$) and Manthedeng village (difference = -2956 to -3789 steps, $p < 0.0001$) compared with the other age and village groupings.

Table 7.2. Adjusted sex-specific descriptive statistics for pedometry variables (full week).

Variables	Male (n = 273)	Female (n = 576)	All (n = 789)
Days compliant ($\geq 10\,000$ steps) *	4.3 (4.0; 4.6)	4.1 (3.8; 4.3)	4.2 (4.0; 4.3)
Average day *			
Full week (7 days)	13 095 (12 498; 13 692)	11 847 (11 409; 12 284)	12 471 (12 107; 12 834)
Weekday (5 days)	12 962 (12 352; 13 573)	11 808 (11 361; 12 255)	12 385 (12 014; 12 757)
Weekend (2 days)	13 426 (12 681; 14 172)	11 943 (11 398; 12 489)	12 685 (12 232; 13 138)
Age quartiles †			
13.7 – 18.4 yrs	14 833 (13 887; 15 779)	12 438 (11 501; 13 375)	13 636 (12 953; 14 318)
18.5 – 28.8 yrs	13 541 (12 531; 14 550)	12 951 (12 103; 13 799)	13 246 (12 584; 13 907)
28.9 – 51.2 yrs	13 559 (12 294; 14 824)	12 045 (11 255; 12 835)	12 802 (12 049; 13 554)
51.3 – 95.7 yrs	9914 (8352; 11 475)	9779 (9034; 10 523)	9846 (8975; 10 718) †
Body-mass-index ‡			
<18.5 kg.m ⁻²	13235 (12143; 14328)	12044 (10295; 13793)	12640 (11601; 13678)
18.5-24.9 kg.m ⁻²	13640 (12919; 14361)	12145 (11533; 12756)	12892 (12410; 13374)
25-29.9 kg.m ⁻²	13056 (11199; 14912)	11509 (10696; 12321)	12282 (11264; 13301)
≥ 30 kg.m ⁻²	10927 (8350; 13504)	11117 (10307; 11926)	11022 (9659; 12385)
Village *			
Madiga	12 468 (11 430; 13 506)	12 421 (11 604; 13 237)	12 445 (11 724; 13 166)
Sephateng	15 158 (14 084; 16 233)	12 774 (11 814; 13 733)	13 966 (13 197; 14 736)
Manthedeng	11 589 (10 219; 12 960)	9084 (8309; 9859)	10 337 (9504; 11 170) **, ††
Combined §	13 299 (11 881; 14 718)	13 100 (11 961; 14 239)	13 200 (12 235; 14 164)

values (number of days and steps.day⁻¹) reported as mean (95%CI); * adjusted for age and body-mass-index; † adjusted for body-mass-index only; ‡ adjusted for age only; § Combined: Ga Tjale – Moduane – Ntsima; || significant difference male vs. female, $p < 0.01$; † Q4: 51.3 – 95.7 yr significantly different to all other quartiles, $p < 0.0001$; ** Manthedeng significantly different to all other villages, $p < 0.0001$; †† significant between-subject interactions: village-sex interaction, $p = 0.0084$

The ambulatory activity of the BMI obese was lower compared with BMI normal (difference = -1843 steps, $p = 0.0785$) (Table 7.2). Overall, subjects recorded the highest and lowest ambulatory levels in spring and autumn, respectively ($p = 0.0273$, data not shown). Pedometer threshold prevalences by sex are reported in Table 7.3.

Table 7.3. Adjusted and unadjusted public health pedometry threshold prevalences by sex.

Categories		Public health pedometry thresholds (steps.day ⁻¹)			
		Sedentary (< 5000)	Low active (5000-7499)	Somewhat active (7500-9999)	Active-very active ($\geq 10\,000$)
Sex	Male	3.3 (9) 2.9 *	4.0 (11) 5.1	14.7 (40) 19.7	78.0 (213) 72.3
	Female	10.9 (56) 10.2	10.9 (56) 9.2	19.0 (98) 17.9	59.3 (306) 62.6
All		8.2 (65) 8.0	8.5 (67) 7.7	17.5 (138) 17.8	65.8 (519) 66.6

values reported as % (N) age-adjusted %; significance for Chi-square test * $p < 0.001$;

Associations were significant across cross-tabular comparisons ($p < 0.001$). Within-subject effects for adjusted ambulatory levels across seven days for sex, age, BMI,

village, season and days $\geq 10\,000$ steps are shown in Figure 7.1A-F. Overall, steps.day^{-1} was higher on Saturday compared with Wednesday (difference = 931 steps, $p = 0.0286$) (Figure 7.1A). Younger age groups showed increasing activity over the week towards Saturday, while the ambulation levels in older age groups were more consistent over the week (Figure 7.1B).

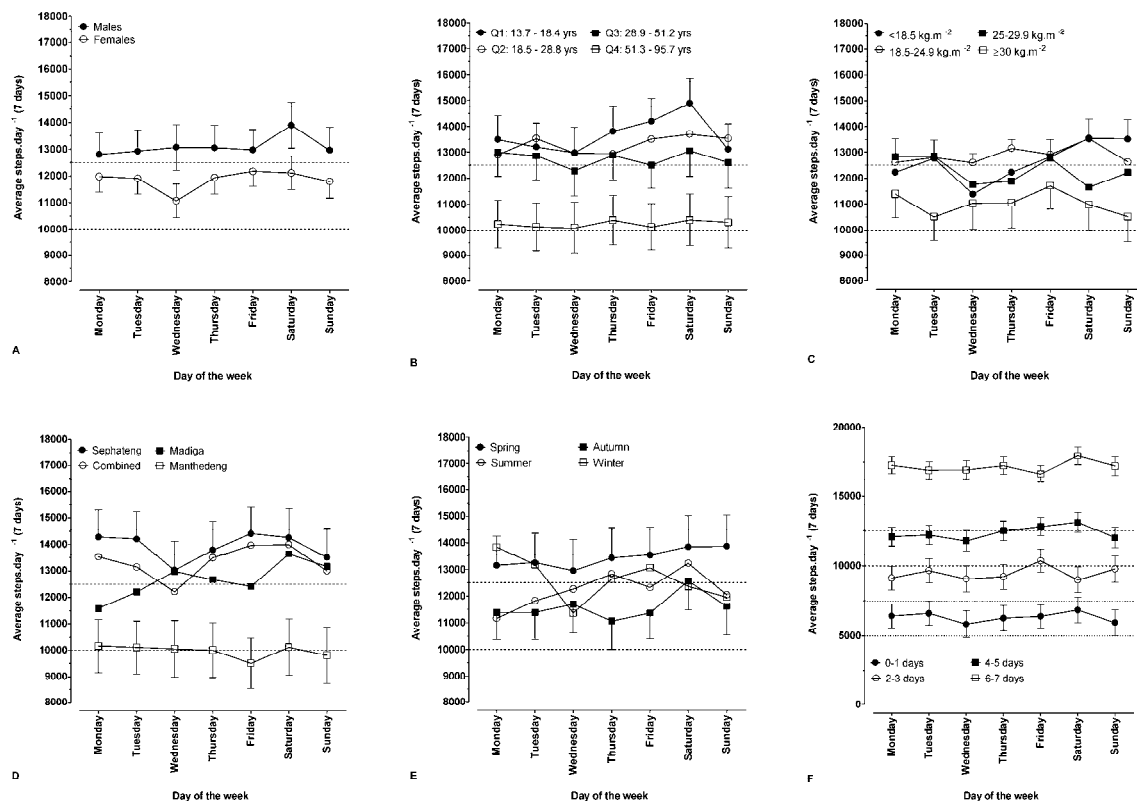


Figure 7.1. Pedometer-assessed ambulatory activity across seven days. A, D, E and F are adjusted for age and body-mass-index; B adjusted for body-mass-index only; C adjusted for age only. A. Sex: sex, $p = 0.0012$. B. Age quartiles: age, $p < 0.0001$. C. Body-mass-index categories. D. Village: village, $p < 0.0001$; village-sex interaction, $p = 0.0084$; day-village interaction, $p = 0.0299$; day-village-sex interaction, $p = 0.0206$. E. Season: season, $p = 0.0418$; season-sex interaction, $p = 0.0187$; day-season interaction, $p = 0.0013$; day-season-sex interaction, $p = 0.0005$. F. Compliance with public health pedometry thresholds ($\geq 10\,000$ steps.day⁻¹): compliance, $p < 0.0001$; compliance-sex interaction, $p < 0.0001$; days-compliance interaction, $p = 0.0237$.

Ambulatory activity did not vary significantly across days for BMI categories, although the obese tended to record lower steps.day^{-1} for most days and the steps.day^{-1} for the underweight and normal weight categories peaked at Saturday (Figure 7.1C). Subjects in Manthedeng village recorded lower ambulation compared with all other villages (Figure 7.1D). Ambulatory activity varied across days

depending on the season with levels higher in spring and lower in autumn (Figure 7.1E). Step counts were relatively constant across the week for all compliance groups, except in particular the 4-5 day compliance group (Saturday > Wednesday) and the 6-7 day compliance group (Saturday > Friday) (Figure 7.1F).

Regression analysis revealed that pedometry-assessed ambulation was inversely and significantly, albeit weakly, associated with adiposity measures, after adjusting for a number of covariates (BMI: zero order $r = -0.27$, partial $r = -0.08$, $p=0.0237$; WC: zero order $r = -0.34$, partial $r = -0.12$, $p=0.0006$). Compared with <5000 steps.day⁻¹, achieving 10 000 steps.day⁻¹, significantly reduced the risk of obesity (BMI: 0.69, 95%CI: 0.52 to 0.92; WC: 0.71, 95%CI: 0.52 to 0.96). The reduction in obesity risk (BMI and WC) was more pronounced at moderate levels of ambulation such that risk changed 29-31% from 5000- to 10 000 steps.day⁻¹, 18-20% from 10 000- to 15 000 steps.day⁻¹, and 13-14% from 15 000- to 20 000 steps.day⁻¹.

The risk of obesity (BMI and WC) was more than two-fold higher in sedentary to low active activity zones compared with the active-to-very active zone (OR = 2.09 to 2.37, $p<0.04$) (OR = 2.09 to 2.37, $p<0.04$). Achieving <10 000 steps.day⁻¹ was associated with a nearly 90% greater risk of obesity compared with achieving 10 000 steps.day⁻¹ (OR = 1.86 to 1.89, $p<0.005$). Because only 15 (1.9%) males were classified as obese (see Table 7.1) we ran the BMI and WC logistic models again only for females and found very similar significance levels, patterns and magnitudes of risk as reported above.

7.4. DISCUSSION

This is a novel study, presenting for the first time an analysis of objectively-measured ambulatory patterns from a health and demographic surveillance site in South Africa's Limpopo Province, and adding to the growing repository of PA data for rural South Africa.^{130,132,135,324,594} The major findings of this study are twofold. Firstly, prevalences for activity and inactivity are substantially different from estimates gleaned from self-reported measures. Secondly, ambulatory levels in the adult, rural population are high because of increased non-leisure, subsistence demands.

Nationally representative estimates of the prevalence of sedentarism in rural South Africans for males and females are 33.6% and 39.2%, respectively, using self-reported measures⁶⁸⁴ which are substantially higher than the age-adjusted 8.0% for <5000 steps.day⁻¹ and 25.5% for 5000-9999 steps.day⁻¹ found in this study. Similarly, Alberts *et al.* reported age-adjusted prevalences of 45-48% for no exercise at home and 17-27% for walking or being physically active at work, in DHDSS adults ≥30 yr of age (n = 2106).¹⁵ However, age-adjusted prevalences for adults ≥30 yr of age in this study (n = 382), were 12-22% for <7500 steps.day⁻¹, 23-25% for 7500-9999 steps.day⁻¹ and 55-63% for ≥10 000 steps.day⁻¹. Because the questionnaire used by Alberts *et al.* was not designed to probe PA performed at low-to-moderate intensities,¹⁵ and since few adults, especially women in the DHDSS participate in sport or exercise, there is the possibility that the PA questionnaire could have displayed a “floor” effect, such that below a certain threshold, important health-contributing PA behaviours were not probed.¹³⁰ From the preceding discussion it would seem that self-report measures are over-reporting sedentarism and under-reporting physically active behaviours, within a rural population in a developing economy. In contrast, results from the 2003-2004 NHANES survey revealed the adherence to PA public health guidelines for self-report measures was 25-33% compared with <10% for accelerometer measurements.⁶⁰⁶ Taken together, these results suggest that reliance solely on self-report measures to assess PA levels might result in dramatic underestimates of the true variation in PA between mostly rural, developing economies and highly urbanised, industrialised economies.

These divergent findings between objective and subjective measures of PA have been suggested to be due to a number of factors.⁶⁰⁶ Firstly, the over-estimation of reported PA might be the result of misclassification of sedentary and light activities as moderate. Secondly, the duration of activities could be over-estimated. Thirdly, subjects may provide relative responses to questions of intensity despite the presentation of intensity examples or physiological cues. Guthold *et al.* have voiced similar concerns about self-report measures,²⁴⁰ suggesting factors such as the interpretation of questions, the understanding of PA intensity and climate, complicate the use of self-report questions across countries and cultures. Interestingly, one South African study (n = 402), using an interview-based questionnaire, has reported

sedentary (8.0%) and moderately active (73.4%) prevalences very similar to our results, in an adult, rural, black population.⁵⁹⁴ This study used a simple adaptation of the IPAQ questionnaire, which excluded questions about leisure because of the lack of leisure-time concept in that population. Instead, IPAQ was adapted around the understanding that walking, carrying a load, constituted a major portion of the day.⁵⁹⁴ In contrast to our findings, females were more active than males, and reported less sedentary behaviour, although not significantly so ($p = 0.275$).⁵⁹⁴

Presently, much of the adult PA in the DHDSS revolves around subsistence-related activities^{13,15,128} while vigorous leisure-time activities are more prevalent in the adolescent age group. Unlike industrialised countries, where leisure-time pursuits tend to dominate adult PA choices,^{306,544} investigations in traditional communities and developing economies have found a wide range of PA levels based on occupation and gender.^{306,323,356,646} Our experience has been that subsistence tasks performed within the household are usually light-to-moderate in intensity, distributed throughout the day. This is in contrast to industrialised productivity which requires high bursts of energy over relatively shorter periods of time.⁴⁶⁹ Within the DHDSS, communal lands are available for planting of crops, such as maize and some vegetables, and cattle grazing.¹³ The lack of electricity in many dwellings would preclude the use of labour saving devices.^{271,336} The use of wood for cooking is still common and requires the manual collection and transport of the raw material or purchasing of wood from sellers coming to the villages. Water is often not available in or around the dwelling, and is collected in containers and transported manually. Journeys to the local store, clinic, communal fields, and to bus or taxi stops are mostly completed on foot, since few DHDSS residents have access to motor vehicle transport within the household.⁵⁷

Pedometry-assessed ambulation levels in an industrialized setting for adults (mean age ± 47 yr) were 44% for sedentarism (< 5000 steps.day⁻¹) and 13.9% for active behaviour ($\geq 10\,000$ steps.day⁻¹).⁶²¹ In contrast, our results for the third and fourth age quartiles revealed prevalences for sedentarism and active behaviour of 5.1% to 70.6% and 19.3% to 36.0%, respectively. A population-based sample of adults ($n = 1102$, ≥ 25 yr) from another industrialized country reported ambulation levels of 10

900 steps.day⁻¹ and 11 200 steps.day⁻¹, for males and females, respectively (difference, $p = 0.34$).¹⁸² The ambulation levels for the same age group in our study was 12 134 steps.day⁻¹ and 10 721 steps.day⁻¹, for males and females, respectively (difference, $p < 0.0008$).

A population-based sample of adults ($n = 704$, ≥ 20 yr) in a developing country has found 44.0% of adults achieved $\geq 10\,000$ steps.day⁻¹ (males: 55.2%; females: 39.1%).²⁴ In comparison, we found a higher prevalence (59.5%) for the same age group (males: 72.1%; females: 55.2%). Moreover, for the 20-30 yr age group we found 20% and 35% higher prevalences for males and females respectively for $\geq 10\,000$ steps.day⁻¹. However, for the ≥ 60 yr age group, prevalences were similar for $\geq 10\,000$ steps.day⁻¹.

Between the ages of 13-18 yr, we found that approximately 35% of adolescents did not meet suggested minimum pedometer thresholds.¹⁸⁶ The recent first South African National Youth Risk Behaviour Study reported that 34.4% of males and 43.0% of females participated in insufficient or no PA.¹⁹ The congruence, especially for males, between estimates for the prevalence of physical inactivity in adolescents from self-reported measures¹⁹ and our objective-measures, is in contrast to the divergence of prevalences in adults. The congruence is likely because self-report of vigorous PA is more accurately recalled⁵⁴⁴ and the greater participation of adolescent youth, particularly males, in vigorous leisure-time PA.¹⁹

As in our earlier study,¹³² we did not find the clearly significant, moderate relationships between ambulation and adiposity that have been found in North American studies⁶¹⁷. Our findings tend to concur with results from South African questionnaire-based physical activity surveys that have found low to modest associations between PA and adiposity³²⁴. The surveys that have found low to modest associations between PA and adiposity.³²⁴ The reasons for the lack of association between adiposity measures and pedometer output are unclear and require further study.

Due to time and financial constraints, the major limitation of the study was the use of convenience sampling. However, using unpublished data collected during a separate DHDSS socio-economic status survey conducted in 2006, there were no significant differences between a socio-economic score for households that participated and those that did not participate in the present survey ($n = 830$, $p=0.657$). Socio-economic and five-day uni-axial accelerometry data collected in the DHDSS found that individuals from households with greater access to motor vehicles, readily available water and electricity supply, and less reliance on wood for cooking purposes are significantly less physically active than individuals from households without motor vehicle access, restricted access to water and reliance on wood for cooking purposes ($n = 138$, $p<0.03$).¹²⁸ Consequently, our sample does not appear to be overly biased based on socio-economic data. A minor aspect was our decision, due to financial constraints, to use a pedometer instead of an accelerometer, which might make comparison problematic with accelerometer-based studies.⁶⁰⁶ However, the NL-2000 is strictly speaking an accelerometer (piezo-electric), with a signal-processing algorithm which reduces the number of false positive signals.¹²⁹ Consequently, our results should be comparable to surveys using accelerometers although a disadvantage was that the NL-2000 does not provide min-by-min data for download to a computer for further analysis.⁶⁰⁶

In conclusion, this novel study reports pedometry-assessed ambulatory levels in a rural, black South African sample. In so doing, objective, unit-based prevalences of various ambulatory levels could be quantified and direct comparisons made with data from various settings.

**CHAPTER 8: EFFECT OF BODY MASS AND PHYSICAL ACTIVITY
VOLUME AND INTENSITY ON PEDOMETRY-MEASURED ACTIVITY
ENERGY EXPENDITURE IN RURAL BLACK SOUTH AFRICANS IN
THE LIMPOPO PROVINCE.**

Data in this chapter has been published in the South African Journal of Sports Medicine 22(1): 3-7, 2010.

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8.1. INTRODUCTION

Pedometry is considered a valid and reliable objective measure of free-living PA.⁴⁴ Moreover, criterion studies using doubly-labelled water^{123,223} and whole-body indirect calorimetry³²⁶ suggest that pedometers provide reasonable estimates of AEE. However, a disadvantage of this methodology is that the primary measure which is usually reported, namely the number of steps, provides no information as to the intensity of the ambulation. Consequently, it is not possible to disentangle the effects of volume and intensity of PA on outcome variables if statistical analyses only consider the number of steps (volume).

We recently reported high ambulation levels (average steps.day⁻¹) for a rural African population in transition but could not provide definitive data pertaining to the intensity at which steps were accumulated.¹²⁷ The study used a piezo-electric based pedometer (NL-2000) which stored both the number of steps and AEE.¹²⁷

The NL-2000 is produced by the Suzuken-Kenz Company (<http://www.suzuken-kenz.com>) for a North American distributor (New Lifestyles, <http://www.new-lifestyles.com>) and is identical in function to the Suzuken-Kenz e-STEP products (personal communication: Hitoshi Ozawa, Suzuken-Kenz, 17-05-2007). Therefore calibration results for the NL-2000 would also be applicable to the Suzuken-Kenz e-STEP products.^{147,537,538} Moreover, because the Suzuken-Kenz range includes the Lifecorder EX, which has been validated,^{326,402} and the technology in this high-end product is essentially the same as the lower-end products (except for the download capacity to a personal computer), the algorithms for all Suzuken-Kenz products would be identical. For instance, the NL-2000 (e-STEP) (personal communication: Operations Manager, New Lifestyles, 02-09-2005) and the Lifecorder EX³²⁶ sense steps when there are three or more acceleration pulses for four consecutive seconds and calculate AEE using body mass (W) and an intensity dependent factor (Ka) such that $AEE\ (kcal) = Ka \times W\ (kg)$.

Consequently, the AEE displayed on the NL-2000 output is a function of the PA intensity (Ka), PA volume (number of steps) and the individual's body mass. It is thus not possible to ascertain if an AEE difference between two individuals is due to increased PA (volume and/or intensity) or because of body mass differences. One approach to circumvent this problem is to use statistical methods to adjust for body mass and PA volume to ascertain whether AEE differences between two individuals are possibly intensity dependent. Therefore the objective of this study was to explore the patterns of pedometry-measured total weekly AEE by statistically adjusting for body mass and PA volume to determine if PA intensity could be an important factor in explaining the high ambulatory levels in a rural African setting.

8.2. METHODS

This analysis uses data for which the study protocol, subjects, field site, sample size and measurements have been described in detail elsewhere.¹²⁷ Briefly, 830 participants from the DHDSS field site^{13-15,131} were conveniently recruited and contacted twice over a 9-day period between January 2005 and December 2007. On the first occasion, subjects were recruited and completed the informed consent, relevant sections of a health questionnaire and provided anthropometric data. Anthropometric measurements and interviews were performed by trained, black local fieldworkers. Subjects were instructed on the required procedures for wearing the pedometer. Nine days later the pedometers were collected and the data recorded by the field workers for later data entry by a trained data capturing clerk. The first author assisted in field worker training and securing funding, and was responsible for construction of a relational database, data management, data analysis and data reporting.

Standard anthropometric measurements included measures of stature (nearest 1 cm) and body mass (nearest 1 kg). We categorised subjects using BMI (underweight: $<18.5 \text{ kg.m}^{-2}$, normal weight: $18.5 - 24.9 \text{ kg.m}^{-2}$, overweight: $25 - 29.9 \text{ kg.m}^{-2}$, obese: $\geq 30 \text{ kg.m}^{-2}$).⁵⁰⁹ Finally, subjects were instructed on the required procedures for wearing the pedometer over 9 consecutive days. We used piezo-electric pedometers (NL-2000, New Lifestyles Inc., Kansas City, MO, USA) not affected by pedometer tilt or adiposity level¹⁴⁶ to objectively measure PA. Data for

day 1 and day 9 were omitted because these were incomplete days. The pedometer was worn on the right waist, securely attached to a nylon belt and sealed with surgical tape. The pedometers could be removed for sleeping and bathing purposes by unclipping the nylon belt. Ambulation PA volume was defined as the average steps.day⁻¹ or steps.wk⁻¹. Energy expenditure was defined as total activity energy expenditure.wk⁻¹ (AEE, kcal.wk⁻¹). We calculated a PA intensity factor (I_{FR} , kcal.kg⁻¹.step⁻¹) from the total weekly steps, total weekly AEE and body mass. Public health indices (thresholds) for steps.day⁻¹ were defined as follows: sedentary: <5 000 steps.day⁻¹, low active: 5 000 - 7 499 steps.day⁻¹, somewhat active: 7 500 - 9 999 steps.day⁻¹, active: 10 000 - 12 499 steps.day⁻¹, and very active: ≥12 500 steps.day⁻¹.⁶¹⁸ A summary variable was created indicating the number of days a subject was compliant or not for 0 - 7 days (≥10 000 steps.day⁻¹). Subjects received a small honorarium on completion of the study. The study was approved by the Ethics Committee of the University of Limpopo (Turfloop Campus).

8.2.1. Statistical analysis

Descriptive statistics comprised means and 95% confidence intervals (95% CI) or one standard deviation (SD). Independent *t*-tests were used to compare variables across gender. Variance components were estimated for inter-individual variance (body mass = kg, PA volume = total weekly steps and I_{FR} = kcal.kg⁻¹.step⁻¹) and residual (intra-individual) variance. The variance components were also expressed as a percentage of the total variance. Inter-individual variance represents true variation between subjects while intra-individual variance represents unexplained variation within subjects. To identify additional variables that could affect the inter-individual variance we entered age and stature as covariates and sex, village and season as fixed factors. Multiple linear regression models, using backward selection, were used to examine the relative importance of PA volume, PA intensity and body mass to AEE. In addition to PA and body mass variables, age and sex were included in all initial models. Significance for variable entry into and exit out of the model were set at $p=0.05$ and $p=0.1$, respectively. Univariate general linear model were used to compare ambulation (steps.day⁻¹) and AEE (kcal.wk⁻¹) across gender, activity categories (sedentary to very active), days of non-compliance/compliance with public health guidelines (≥10 000 steps.day⁻¹), and obese- or normal-weight inactive (<7

500 steps.day⁻¹), active (10 000 - 12 499 steps.day⁻¹) and very active ($\geq 12\,500$ steps.day⁻¹) participants. All initial models adjusted for age and body mass. Additional AEE models were also constructed which adjusted for age, body mass and steps.wk⁻¹. *Post hoc* multiple comparison analyses (Sidak's *t*-test) assessed group differences. Data were analysed using appropriate statistical software (SPSS version 17.0.2). Significance for all inferential statistics was set at $p < 0.05$.

8.3. RESULTS

We excluded 14 outliers identified during exploratory data analysis. Because of very few obese males in the sample (Table 8.1), only adult (19 - 65 yr) female subjects were used in the obese/normal weight comparison across activity categories.

Table 8.1. Descriptive characteristics for rural and urban women.

	Residence		
	Female (N=508)	Male (N=267)	<i>p</i> [†]
Continuous variables			
Age (yr)	40.1 ± 20.7	28.4 ± 17.6	<0.0001
Body-mass-index (kg.m ⁻²)	26.6 ± 6.4	21.2 ± 3.9	<0.0001
Average steps.day ⁻¹	11086 ± 4538	14028 ± 5434	<0.0001
Average activity EE (kcal.day ⁻¹)	393 ± 189	491 ± 213	<0.0001
Intensity factor (kcal.kg ⁻¹ .step ⁻¹ x1000)	0.58 ± 0.28	0.65 ± 0.41	0.0032
Categorical variables *			
Body mass index classification			
Normal weight (<25 kg.m ⁻²)	47.8 (243)	87.6 (234)	<0.0001
Obese (≥30 kg.m ⁻²)	27.2 (138)	4.1 (11)	<0.0001
Physical activity classification			
Inactive (<5000 steps.day ⁻¹)	10.2 (52)	3.0 (8)	0.0006
Active (≥10 000 steps.day ⁻¹)	59.4 (302)	77.9 (208)	<0.0001
Completion of secondary school (≥Grade 12)	16.5 (58)	14.1 (29)	0.5420
Ownership of motor vehicle (Yes)	21.2 (99)	18.1 (45)	0.3911
Electricity available inside house (Yes)	75.4 (353)	65.3 (162)	0.0055
Water collected outside dwelling (Yes)	8.5 (40)	8.1 (20)	0.9363

Data are reported as mean ± SD for all continuous variables and % (*N*) for * categorical variables, † *p* values evaluate female v. male differences.

The sizeable variance attributed to body mass (13.1%), PA volume (total weekly steps, 56.9%) and *I*_{FR} (kcal.kg⁻¹.step⁻¹, 24.4%) suggested further analysis was warranted to determine if AEE group differences persist, possibly due to an intensity effect, by adjusting for body mass and PA volume. The 5.5% error variance was likely due to the rather crude *I*_{FR} that was calculated. Entering age or stature as covariates, and sex, village or season as fixed factors, made no difference to variances (<1%). Because the data were collected over 2 years in a number of

villages that differ in terms of infrastructure and access to public transport, it was important to test whether season and village could explain part of the variance. PA volume, I_{FR} and body mass were significant predictors of AEE (model and coefficients: $p < 0.0001$, model adjusted $R^2 = 0.814$) and part correlations were 0.887, 0.355 and 0.259, respectively. The multiple linear regression analysis revealed no collinearity between variables (variance inflation factors < 1.2).

The adjusted R^2 for the partially (age and body mass) and fully (age, body mass and steps. wk^{-1}) adjusted AEE general linear model models ranged from 0.130 to 0.564 and 0.690 to 0.695, respectively ($p < 0.0001$). Males accumulated significantly more steps than females (687 steps. day^{-1} , $p < 0.0001$). (Figure. 8.1). The fully adjusted AEE was not significantly different (78 kcal. wk^{-1} , $p = 0.2552$) between sexes, suggesting no intensity effect (Figure. 8.1). However, adjusting for age and body mass only resulted in a significant difference (224 kcal. wk^{-1} , $p = 0.0017$), suggesting that volume plays a more significant role in AEE differences between sexes.

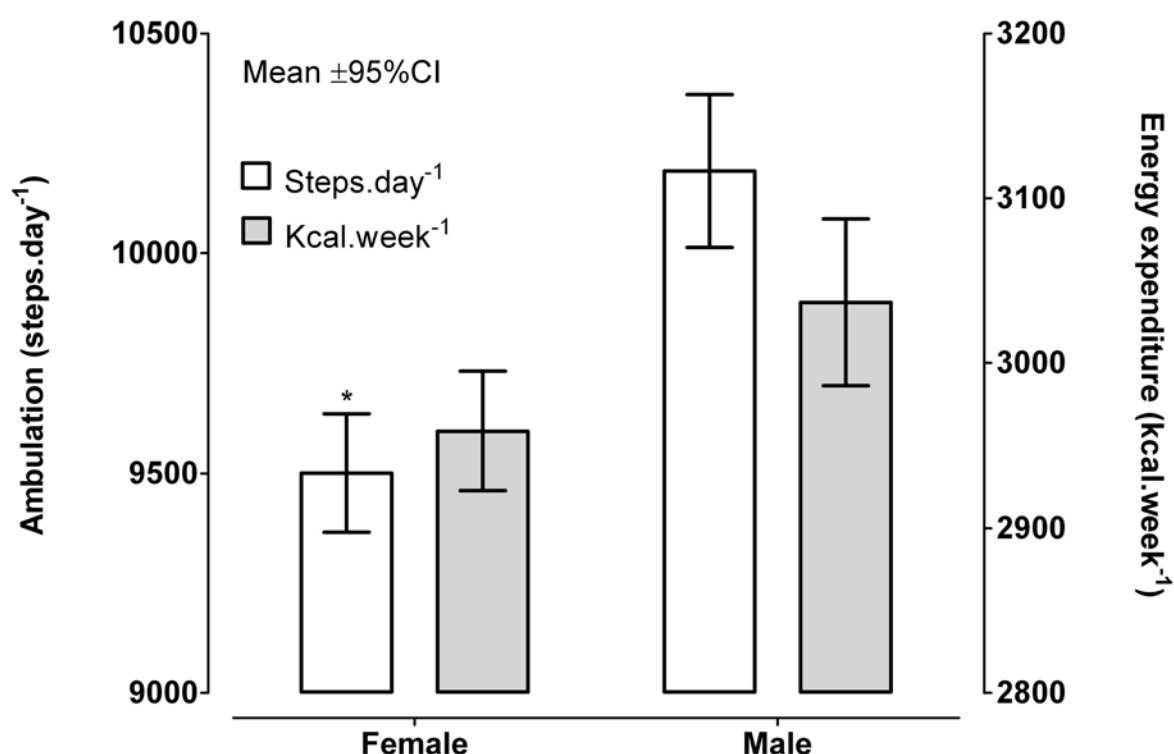


Figure 8.1. Ambulatory and energy expenditure levels for males and females. Steps. day^{-1} adjusted for age and body mass. Kcal. wk^{-1} adjusted for age, body mass and steps. wk^{-1} . * Steps. day^{-1} : males > females, $p < 0.0001$.

Age and body mass-adjusted differences in steps across categories (sedentary - very active) were significant for all pairwise comparisons ($1\,783\text{ steps}\cdot\text{day}^{-1}$ to $9\,710\text{ steps}\cdot\text{day}^{-1}$, $p<0.0001$) (Figure. 8.2). Adjusted for age and body mass, the middle three categories (low-active to active) resulted in relatively similar AEE, ($p>0.1$), but not so for two the extreme AEE categories (sedentary v. very active, $p<0.04$). However, the fully adjusted model yielded no significant differences across activity categories, suggesting a significant volume effect ($p>0.1$) (Figure 8.2).

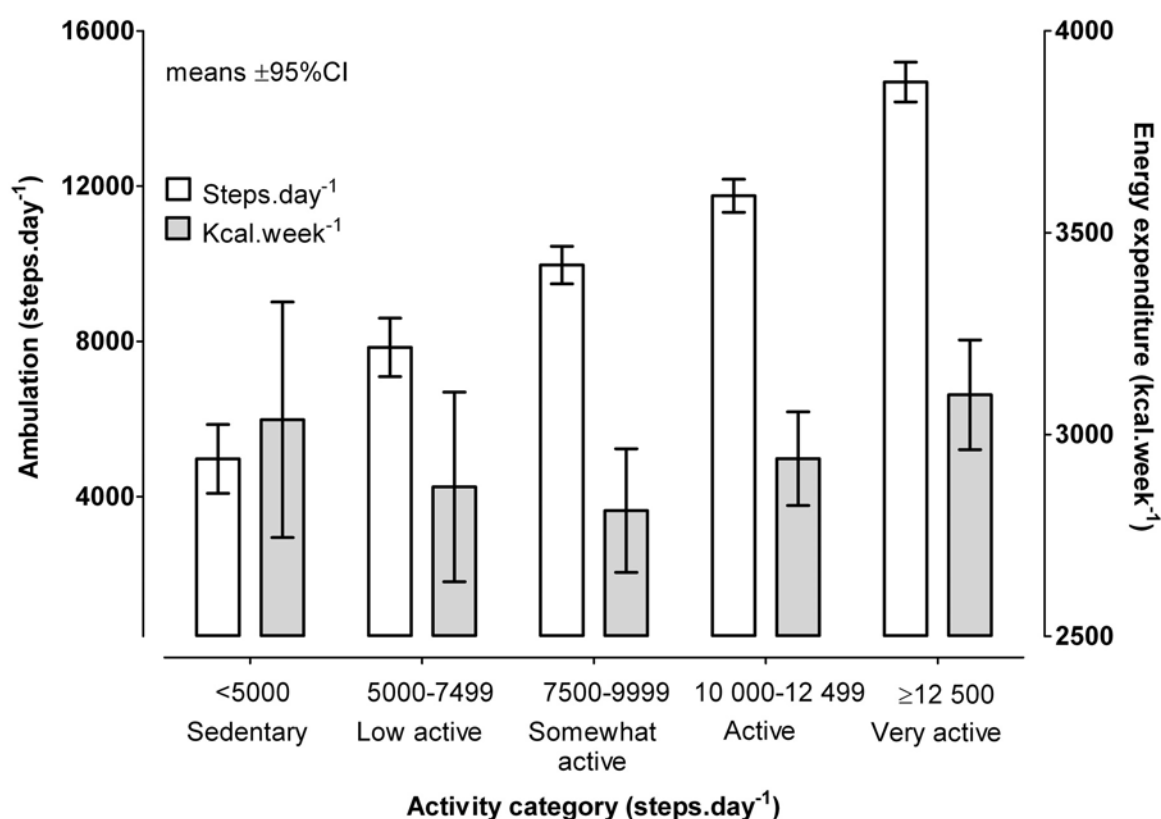


Figure 8.2. Ambulatory and energy expenditure levels across activity categories. Steps. day^{-1} adjusted for age and body mass. Kcal. wk^{-1} adjusted for age, body mass and steps. wk^{-1} . Steps. day^{-1} : all activity categories significantly different, $p<0.0001$.

Age and body mass-adjusted steps. day^{-1} for 6 - 7 days of compliance with public health guidelines ($\geq 10\,000\text{ steps}\cdot\text{day}^{-1}$) were significantly different to all other levels of compliance ($p<0.003$) but there were no significant differences between 0 days (non-compliance) and 1 - 5 days of compliance ($p>0.4$) (Figure. 8.3). Adjusted for age and body mass, AEE differed significantly for days of compliance ≥ 6 compared with non-compliance (0 days) and lower levels of compliance (1 - 5 days) ($p<0.03$). Significant differences persisted only for AEE for 6 - 7 days of compliance versus 1 -

2 days of compliance ($p < 0.04$), suggesting an intensity effect only for 6 - 7 days of compliance (Figure. 8.3).

The AEE, adjusted for age and body mass of highly active normal weight and obese women was significantly higher than inactive normal weight and obese women (difference: 2 224 – 2 403 kcal.wk⁻¹, $p < 0.0001$). Adjusted for age, body mass and steps.wk⁻¹, obese and normal weight adult females did not differ in AEE for the three PA categories, suggesting that there are no statistical differences in PA intensity (Figure. 8.4). However, there was a tendency for normal weight females to have higher AEE (200 kcal.wk⁻¹ to 592 kcal.wk⁻¹, $p > 0.30$).

8.4. DISCUSSION

This is a novel study reporting for the first time volume and intensity effects from data obtained using pedometers. The analysis has highlighted an intensity effect for days of compliance and especially at very active ambulatory levels ($\geq 12\,500$ steps.day⁻¹). Interestingly, there did not seem to be a significant intensity effect between sexes, activity categories or obese versus normal weight across activity categories once age, body mass and accumulated steps had been adjusted for. Differences in accumulated steps between males and females have been reported.^{405,623} Our results suggest that it is the difference in PA volume, and not PA intensity, that explains the difference in AEE between males and females from this rural, African setting. Although average step totals increased significantly across activity categories, adjusted AEE did not increase accordingly. We also did not find markedly increased adjusted AEE between obese and normal weight females across activity categories, which is in agreement with findings of similar gross EE for walking and jogging at the same speed between normal weight and overweight/obese women, once adjusted for body mass and free fat mass.³⁴¹ Furthermore, non-compliance or compliance on 1 - 5 days of the week with public health guidelines ($\geq 10\,000$ steps.day⁻¹)⁶²² did not seem to reveal differences in AEE. However, complying on 6 - 7 days, required significant increases in volume and intensity. These results suggest that public health PA guidelines of at least 5 times per week, 30 min per session,²⁵⁷ which equates to approximately 10 000 steps.day⁻¹,^{285,339,373} were likely

met through increases in accumulated steps throughout the day instead of increasing PA intensity.

It was interesting that these findings would seem to provide non-intervention, free-living support for the feasibility of promoting moderate intensity PA such that the lack of a vigorous intensity requirement would not be a barrier to increasing PA. In other words, our results suggest that within this rural African population, walking behaviours are naturally modelled according to public health PA guidelines. However, highly active groups such as those achieving $\geq 12\,500$ steps on 6 or more days a week, required increases in intensity. This finding is in accord with the significantly higher accelerometer-measured moderate-to-vigorous PA recorded for subjects achieving $\geq 11\,762$ steps.day⁻¹ compared with those achieving $\leq 8\,123$ steps.day⁻¹; 68.6 min v. 23.6 min, respectively ($p=0.000$).³⁷³

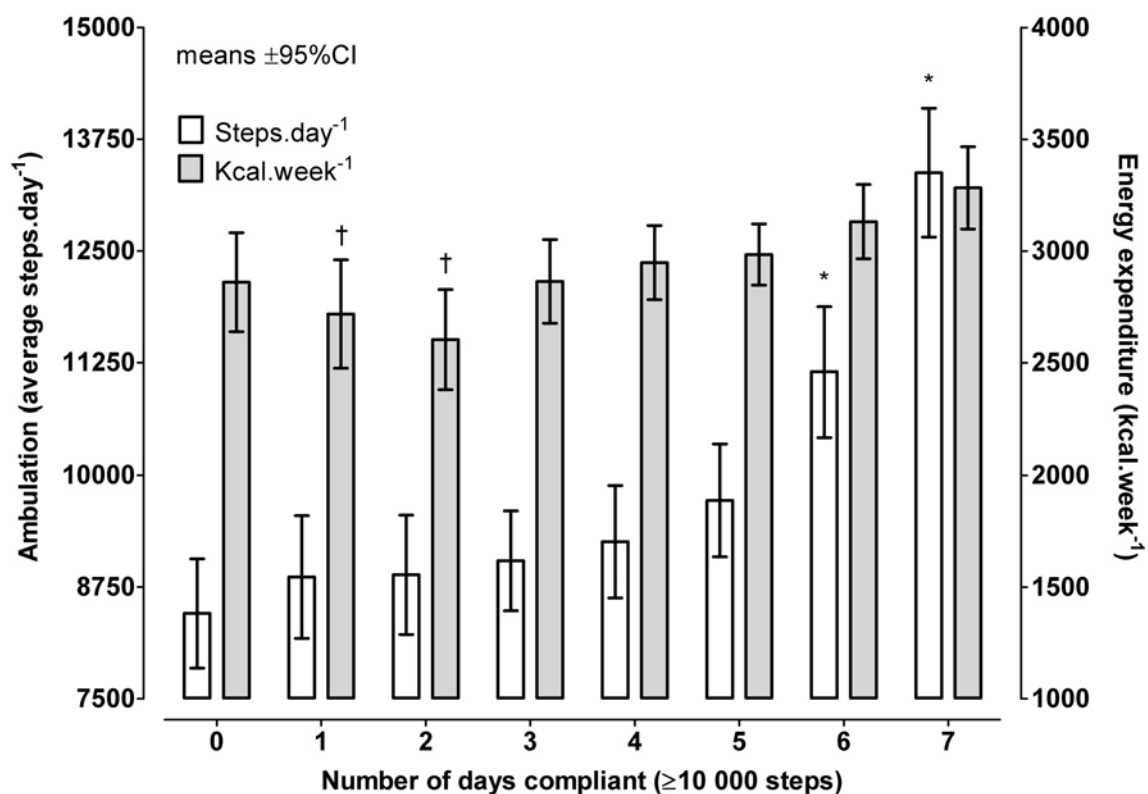


Figure 8.3. Ambulatory and energy expenditure levels across number of days compliant ($\geq 10\,000$ steps.day⁻¹). Steps.day⁻¹ adjusted for age and body mass. Kcal.wk⁻¹ adjusted for age, body mass and steps.wk⁻¹. * Steps.day⁻¹: 6 days and 7 days significantly different to days 6 - 7, $p<0.04$.

Le Masurier *et al.* also reported higher moderate-to-vigorous activity for subjects achieving $\geq 10\,000$ steps.day⁻¹ compared with $<10\,000$ steps.day⁻¹ whether accumulated in bouts ≥ 1 -, ≥ 5 - or ≥ 10 min (difference: $p < 0.05$).³³⁹ Recently, Dugas *et al.* suggested that PA intensity and not PA volume was a greater determinant of adiposity in young, black South African urban dwellers.¹⁶⁸ Our results would suggest that the PA volume is the dominant contributor to AEE in rural dwellers. Moreover, we have shown that average steps.day⁻¹ is significantly associated with adiposity levels in rural African women ($r = -0.20$, $p = 0.032$).¹³²

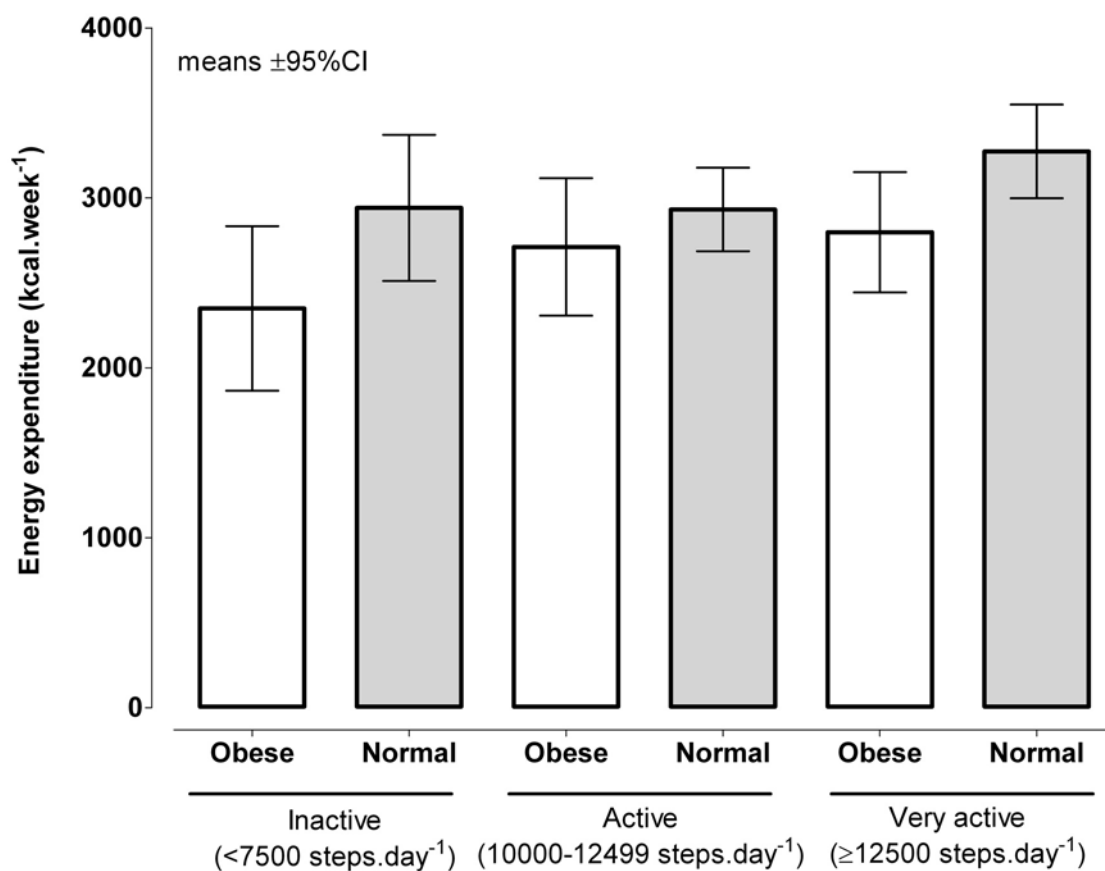


Figure 8.4. Ambulatory and energy expenditure levels for normal weight and obese women across activity categories. Kcal.wk⁻¹ adjusted for age, body mass and steps.wk⁻¹.

Several limitations must be acknowledged. Firstly, we could not compare our statistical adjustment against actual volume and intensity measures. Future analyses using uni-axial accelerometer data to ascertain at which intensity levels steps are being accumulated would provide more definitive answers as to the relative importance of PA volume and intensity, specifically within the context of a rural

African setting. Secondly, the absolute AEE values reported in this study should be carefully interpreted because treadmill calibration studies for the NL-2000 suggest an overestimation of approximately 25% for AEE.¹⁴⁷

In conclusion, we have highlighted an intensity effect for 6 - 7 days of compliance and at very active ambulatory levels. A volume effect appeared to dominate between sexes, across activity categories and weight-by-activity categories and would suggest that public health messages in this specific rural setting should focus on maintaining PA volume through daily living rather than advocating increases in PA intensity. It is important that *post hoc* statistical adjustments be made for body mass and PA volume when comparing AEE data across groups.

University of Cape Town

**CHAPTER 9: COMPLIANCE WITH PHYSICAL ACTIVITY
GUIDELINES IN RURAL, BLACK SOUTH AFRICANS IN THE
LIMPOPO PROVINCE: AN ENERGY EXPENDITURE APPROACH.**

Data in this chapter has been published in the British Journal of Sports Medicine 45:
619-625, 2011.

University of Cape Town

9.1. INTRODUCTION

The data output provided by pedometers, namely steps per day, while easily understood, is problematic when attempting to reconcile with PA guidelines which typically include intensity, frequency and volume of PA.^{257,288} Investigators have reported the number of daily steps^{285,339,373,664,679} or stepping rate^{383,631} required to comply with the ACSM guideline of 150 min.wk⁻¹ (30 min of moderate-to-vigorous PA five or more days per wk).²⁵⁷ General consensus is that 10000 steps.day⁻¹ provides a sufficient guide to achieve the ACSM guideline.^{285,339,622,679} However, the IOM guideline, which focuses on energy balance rather than all-cause mortality, requires 420 min.wk⁻¹ (60 min.day⁻¹ of moderate-to-vigorous PA on seven days.wk⁻¹).²⁸⁸ Tudor-Locke *et al.* suggest 11 000 to 13 000 steps.day⁻¹ might be required to achieve the IOM guideline, but provide no substantive evidence for these intensity thresholds.⁶²²

We have recently reported high ambulation levels for a rural African sample and suggested on the basis of step counts alone that the sample was active to very active, and that nationally representative self-report surveys might by over-reporting physical inactivity and under-reporting physical activity.¹²⁷ However, because of the nature of the pedometer output, we could not directly report intensity nor relate the average daily step counts to PA guidelines^{257,288} other than inferring from step counts guidelines¹²⁷ or using statistical methods to deduce possible volume or intensity effects.¹³³

Recently, Mudd *et al.* used an EE-based method to ascertain the compliance of North American adults with ACSM and IOM guidelines.⁴³¹ Instead of using conventional criteria such as duration, frequency and discrete intensity categories to determine whether an individual complies with PA guidelines, Mudd *et al.* argue that the calculation of EE from duration, frequency and intensity measures might avoid misclassifying individuals who meet the intent of the PA guidelines in terms of total EE.⁴³¹ Consequently, the EE-based approach utilizes units such as kcal.kg⁻¹ per unit of time (hr, day or week), and because the NL-2000 pedometer^{147,537,538} stores AEE

in kcal it would seem feasible to explore the possibility of adapting the approach of Mudd *et al.* to pedometer data.

Therefore the objectives of this study were first to examine more directly with pedometer data the compliance estimates for PA guidelines in a rural African setting. Second, to determine the average daily step counts associated with compliance of PA guidelines. Third, to ascertain whether complying partially or fully with different PA guidelines is associated with changes in the risk associated with adiposity.

9.2. METHODS

9.2.1. Protocol, subjects and measurements

This analysis uses data for which the study protocol, subjects, field site, sample size and measurements have been described in detail elsewhere.¹²⁷ Briefly, 830 participants from the DHDSS field site^{13-15,131} were conveniently recruited and contacted twice over a nine day period between January 2005 and December 2007. On the first occasion, subjects were recruited and completed the informed consent, relevant sections of a health questionnaire and provided anthropometric data. Anthropometric measurements and interviews were performed by trained, black local fieldworkers. Subjects were instructed on the required procedures for wearing the pedometer. Nine days later the pedometers were collected and the data recorded by the field workers for later data entry by a trained data capturing clerk. The first author assisted in field worker training and securing funding, and was responsible for construction of a relational database, data management, data analysis and data reporting. Standard anthropometric measurements included measures of stature (nearest 1 cm) and body mass (nearest 1 kg). We categorized subjects using BMI from underweight to obese.⁵⁰⁹ Finally, subjects were instructed on the procedures for wearing the pedometer over nine consecutive days. We used piezo-electric pedometers (NL-2000, New Lifestyles Inc., Kansas City, MO, USA), with a seven day memory function and not affected by pedometer tilt (approximately 15 degrees) or adiposity level,¹⁴⁶ to objectively measure PA. The NL-2000 output includes daily step counts and AEE. The AEE for each valid step is calculated using body mass (W) and an intensity dependent factor (Ka) such that $AEE \text{ (kcal)} = Ka \times W \text{ (kg)}$.¹³³

Data for day 1 and day 9 were omitted because these were incomplete days. The pedometer was worn on the right waist, securely attached to a nylon belt and sealed with surgical tape. The pedometers could be removed for sleeping and bathing purposes by unclipping the nylon belt. Subjects received a small honorarium on completion of the study. The study was approved by the Ethics Committee of the University of Limpopo.

9.2.2. Pedometer data and energy expenditure calculations

Public health indices for steps.day⁻¹ were defined from sedentary to very active.⁶¹⁸ A summary variable was created indicating the number of days a subject was compliant or not for 0-7 days (≥10 000 steps.day⁻¹).

The NL-2000 over-predicts AEE by ≈25% across treadmill speeds of 3.25 to 5.64 km.hr⁻¹, and ≈15% at 6.42 km.hr⁻¹.¹⁴⁷ Consequently, a 25% correction factor was applied to the raw AEE data prior to any analyses. Adapting the approach of Mudd *et al.*⁴³¹ to pedometer data we reduced the daily AEE data as follows:

$$\text{Daily AEE} = (\text{Raw Daily AEE} \times 0.75) / \text{body mass} = \text{kcal.kg}^{-1}.\text{day}^{-1}$$

From the daily AEE a weekly total was obtained:

$$\text{Weekly AEE} = \sum \text{Daily AEE} = \text{kcal.kg}^{-1}.\text{wk}^{-1}$$

From the daily and weekly AEE non-compliance/compliance categories were derived based on the following definitions:⁴³¹

ACSM guideline: 5 days.wk⁻¹, 30 min.session⁻¹, 3 METs ≈ 3 kcal.kg⁻¹.hr⁻¹;

$$1 \text{ day} \times (0.5 \text{ hr} \times 3 \text{ kcal.kg}^{-1}.\text{hr}^{-1}) = 1.5 \text{ kcal.kg}^{-1}.\text{day}^{-1}$$

$$5 \text{ days} \times (0.5 \text{ hr} \times 3 \text{ kcal.kg}^{-1}.\text{hr}^{-1}) = 7.5 \text{ kcal.kg}^{-1}.\text{wk}^{-1}$$

IOM guideline: 7 days.wk⁻¹, 60 min.session⁻¹, 3 METs ≈ 3 kcal.kg⁻¹.hr⁻¹;

$$1 \text{ day} \times (1 \text{ hr} \times 3 \text{ kcal.kg}^{-1}.\text{hr}^{-1}) = 3 \text{ kcal.kg}^{-1}.\text{day}^{-1}$$

$$7 \text{ days} \times (1 \text{ hr} \times 3 \text{ kcal.kg}^{-1}.\text{hr}^{-1}) = 21 \text{ kcal.kg}^{-1}.\text{wk}^{-1}$$

Non-compliance: $<7.5 \text{ kcal.kg}^{-1}.\text{wk}^{-1}$

ACSM compliance: $\geq 7.5 \text{ kcal.kg}^{-1}.\text{wk}^{-1}$, $\geq 1.5 \text{ kcal.kg}^{-1}.\text{day}^{-1}$ for $\geq 5 \text{ days.wk}^{-1}$

IOM compliance: $\geq 21 \text{ kcal.kg}^{-1}.\text{wk}^{-1}$, $\geq 3 \text{ kcal.kg}^{-1}.\text{day}^{-1}$ for 7 days.wk⁻¹

Full compliance with either guideline demanded that the required weekly AEE (volume) and also the minimum frequency of the required daily AEE (frequency) be met. Where compliance with ACSM guidelines only was required the volume range was ≥ 7.5 - to $<21 \text{ kcal.kg}^{-1}.\text{wk}^{-1}$.

9.2.3. Statistical analysis

Descriptive statistics comprised means and 95% confidence intervals (95%CI) or one standard deviation (SD), and prevalence (%). Post-stratification weights by age and sex were derived from the DHDSS population¹³¹ to adjust for bias introduced through convenience sampling and applied to all subsequent procedures except basic descriptive statistics and independent t-tests which were used to compare variables across gender. Weighted prevalence estimates for non-compliance/compliance with public health guidelines were age-standardized according to the world population.⁷ Univariate general linear models were used to compare ambulation (steps.day^{-1}) across non-compliance/compliance with public health guidelines and BMI category. All general linear models were adjusted for age. *Post hoc* multiple comparison analyses (Sidak's t-test) assessed group differences. To investigate the risk of obesity in relation to non-compliance/compliance with public health guidelines, odds ratios (OR $\pm 95\%$ CI) were derived from binary logistic regression models for BMI- defined obesity adjusting for age, sex and season. Hosmer-Lemeshow statistics were calculated for each logistic regression model. Data were analysed using appropriate statistical software (SPSS version 17.0.2, SPSS Inc., Chicago, USA, 2009). Significance for all inferential statistics was set at $p < 0.05$.

9.3. RESULTS

Raw data are reported for the descriptive statistics in Table 9.1. Of the 789 subjects that provided pedomtery data, we excluded 14 data points (8 females, 6 males)

identified as extreme values for average daily AEE (≥ 3 times the interquartile range or one of the five highest or lowest values) after checking for any data entry errors. The significant between-group ($p < 0.0001$), age-adjusted average daily steps for non-compliance, ACSM-only compliance and IOM compliance were 6 420 (4 792 to 8 048) steps.day⁻¹, 10 837 (10 340 to 11 335) steps.day⁻¹ and 14 552 (13 962 to 15 142) steps.day⁻¹, respectively.

Table 9.1. Descriptive characteristics for rural men and women.

	Female (n = 508)	Male (n = 267)	P
Continuous variables			
Age (yr)	40.1 (20.7)	28.4 (17.6)	<0.0001
Body mass (kg)	66.7 (16.3)	59.3 (11.8)	<0.0001
Body-mass-index (kg.m ⁻²)	26.6 (6.4)	21.2 (3.9)	<0.0001
Average steps.day ⁻¹	11086 (4538)	14028 (5434)	<0.0001
Average activity energy expenditure (kcal.day ⁻¹)	393 (189)	491 (213)	<0.0001
	4.6 (2.5)	6.5 (3.1)	<0.0001
Categorical variables *			
Body mass index classification			
Normal weight (<25 kg.m ⁻²)	47.8 (243)	87.6 (234)	<0.0001
Obese (≥ 30 kg.m ⁻²)	27.2 (138)	4.1 (11)	<0.0001
Physical activity classification			
Inactive (<5000 steps.day ⁻¹)	10.2 (52)	3.0 (8)	0.0006
Active (≥ 10000 steps.day ⁻¹)	59.4 (302)	77.9 (208)	<0.0001
Compliance with physical activity guidelines			
Non-compliance [†]	10.4 (53)	4.1 (11)	<0.0038
Complies with ACSM only [‡]	58.3 (296)	40.4 (108)	<0.0001
Complies with IOM [§]	31.3 (159)	53.4 (148)	<0.0001
Socio demographic descriptors			
Completion of secondary school (\geq Grade 12)	16.5 (58)	14.1 (29)	0.5420
Ownership of motor vehicle (Yes)	21.2 (99)	18.1 (45)	0.3911
Electricity available inside house (Yes)	75.4 (353)	65.3 (162)	0.0055
Water collected outside dwelling (Yes)	8.5 (40)	8.1 (20)	0.9363

unadjusted data, reported as mean (SD) for all continuous variables except * categorical variables % (n), [†] <7.5 kcal.kg⁻¹.wk⁻¹, [‡] ACSM (American College of Sports Medicine): ≥ 7.5 but <21 kcal.kg⁻¹.wk⁻¹, ≥ 1.5 kcal.kg⁻¹.day⁻¹, ≥ 5 days.wk⁻¹, [§] IOM (Institute of Medicine): ≥ 21 kcal.kg⁻¹.wk⁻¹, ≥ 3 kcal.kg⁻¹.day⁻¹, 7 days.wk⁻¹, ^{||} *p* values evaluate female vs. male differences.

Less than 10% of subjects did not comply with the ACSM or IOM guidelines and 2.4-fold more females than males did not comply with any PA guidelines (Figure 9.1). Nearly 1.5-fold more females than males complied with ACSM, and in contrast, 1.6-fold more males compared with females complied with the IOM guidelines. DHDSS prevalence estimates for compliance with ACSM and IOM guidelines, adjusted to the world population, ranged from 37.2% to 55.0%, respectively (Figure 9.1). Nearly 75% of subjects complying with IOM guidelines achieved $\geq 10\,000$ steps on 6-7 days of the week (Figure 9.2). In contrast, 65.4% subjects not complying with any PA guidelines achieved 10000 steps on only one day of the week or not at all.

Compliance with ACSM guidelines was relatively evenly distributed across categories within a range of 21.9% (Figure 9.2).

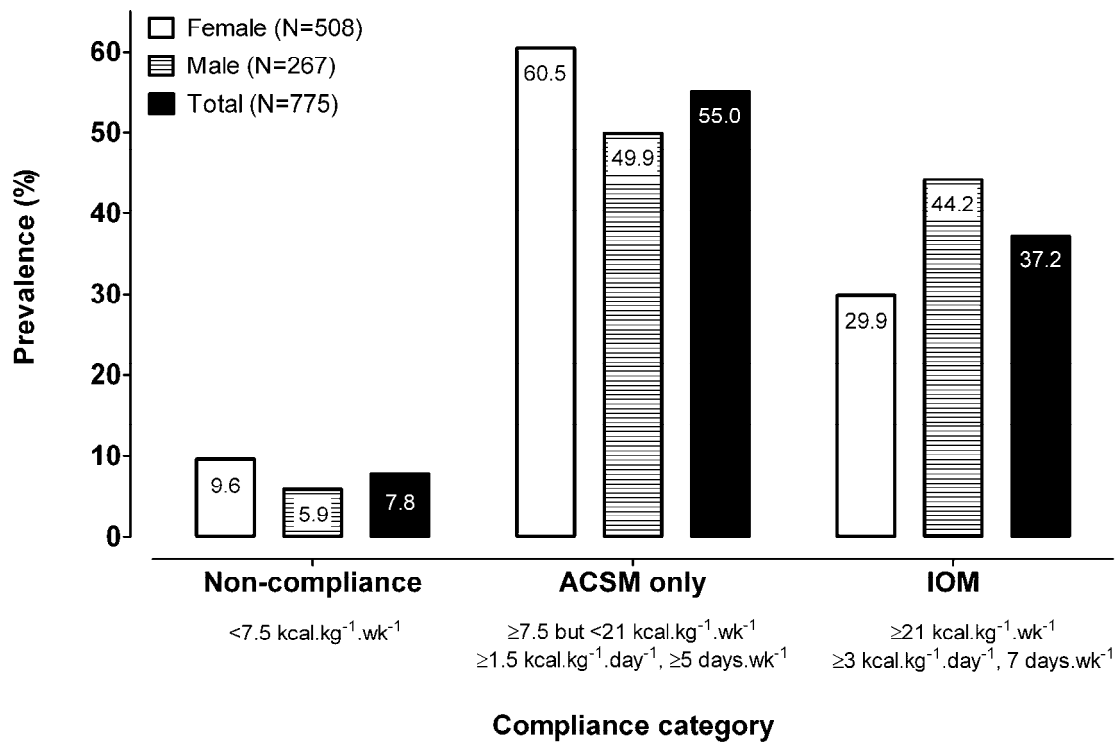


Figure 9.1. Prevalence of non-compliance and compliance with ACSM and IOM physical activity guidelines in rural African males and females. Percentages are weighted to the DHDSS population and age-standardised to the world population.

Irrespective of BMI, there was a systematic increase in average steps.day⁻¹ across non-compliance/compliance categories (Figure 9.3). The interaction term (BMI category x non-compliance/compliance category) for the general linear model was significant ($p=0.0048$). The range of average steps.day⁻¹ for non-compliance, ACSM compliance and IOM compliance was 5 836 – 6 688 steps.day⁻¹, 8 621 – 12 293 steps.day⁻¹ and 13 015 – 15 330 steps.day⁻¹, respectively. Within non-compliance/compliance categories, the 95%CI for the overweight and obese subjects overlapped the 95%CI for under- and normal weight subjects, suggesting no significant differences in average steps.day⁻¹ between BMI <25 kg.m⁻² and BMI ≥25 kg.m⁻².

Compared with non-compliance with any PA guideline, the risk of BMI-defined obesity was 48.9% lower ($p=0.0647$) and 87.3% lower ($p<0.0001$) for ACSM-only compliance and IOM compliance, respectively. The Hosmer-Lemeshow statistic was not significant ($p=0.3976$).

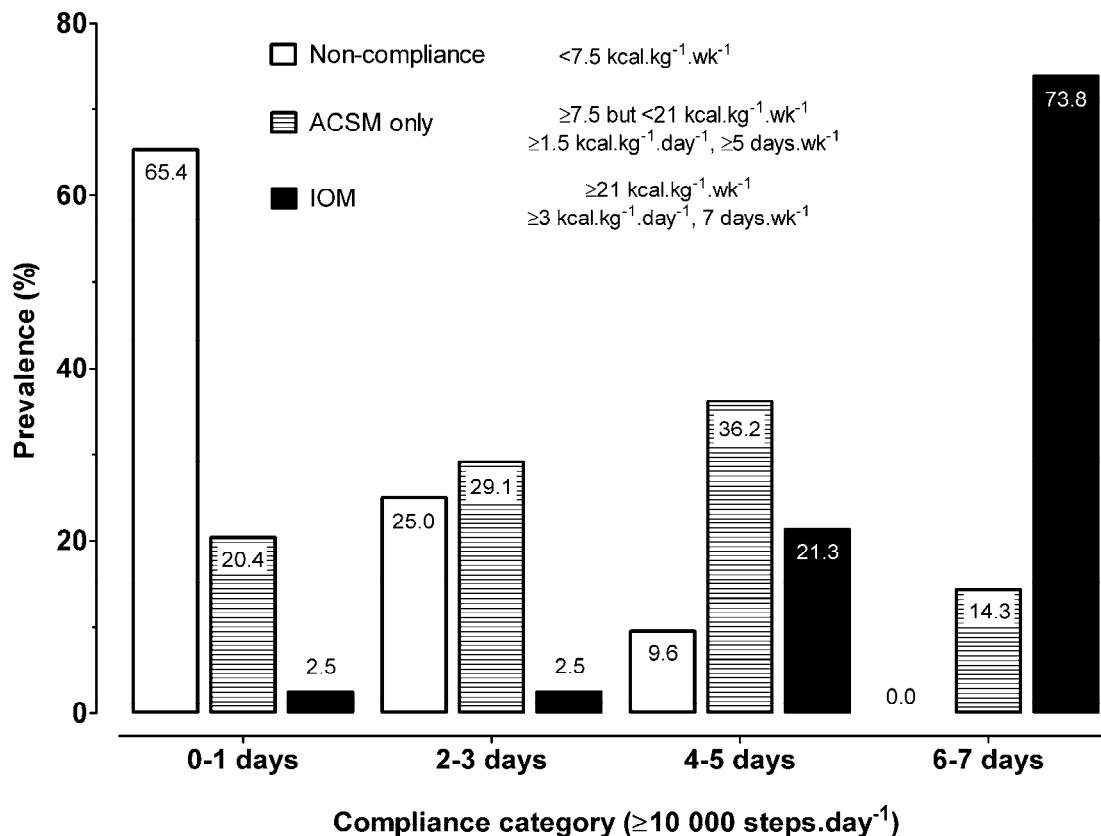


Figure 9.2. Prevalence of non-compliance and compliance with ACSM and IOM physical activity guidelines in the DHDSS sample across compliance categories for achieving $\geq 10\,000$ steps.day⁻¹. Percentages are weighted to the DHDSS population.

Full compliance (volume and frequency) or partial compliance (volume only) with the ACSM guidelines was not associated with a statistically lower risk of BMI-defined obesity ($p>0.07$) (Figure 9.4). In contrast IOM partial and full compliance carried a 42.1% ($p=0.0399$) and 84% ($p<0.0001$) lower risk of BMI-defined obesity. The Hosmer-Lemeshow statistic was not significant for the ACSM model ($p=0.3656$), but was significant for the IOM model ($p=0.0212$).

9.4. DISCUSSION

Using a novel approach to pedometer data, we have shown that as with the steps per day data, AEE data suggests possible discrepancies between the prevalence estimates of objective and self-report measures for physical inactivity/activity, specifically in rural, African populations. Second, the average daily step counts associated with compliance of ACSM and IOM guidelines are in agreement with proposed thresholds. Third, compliance with IOM guidelines, but not compliance with ACSM guidelines, is associated with a statistically significant reduced obesity risk.

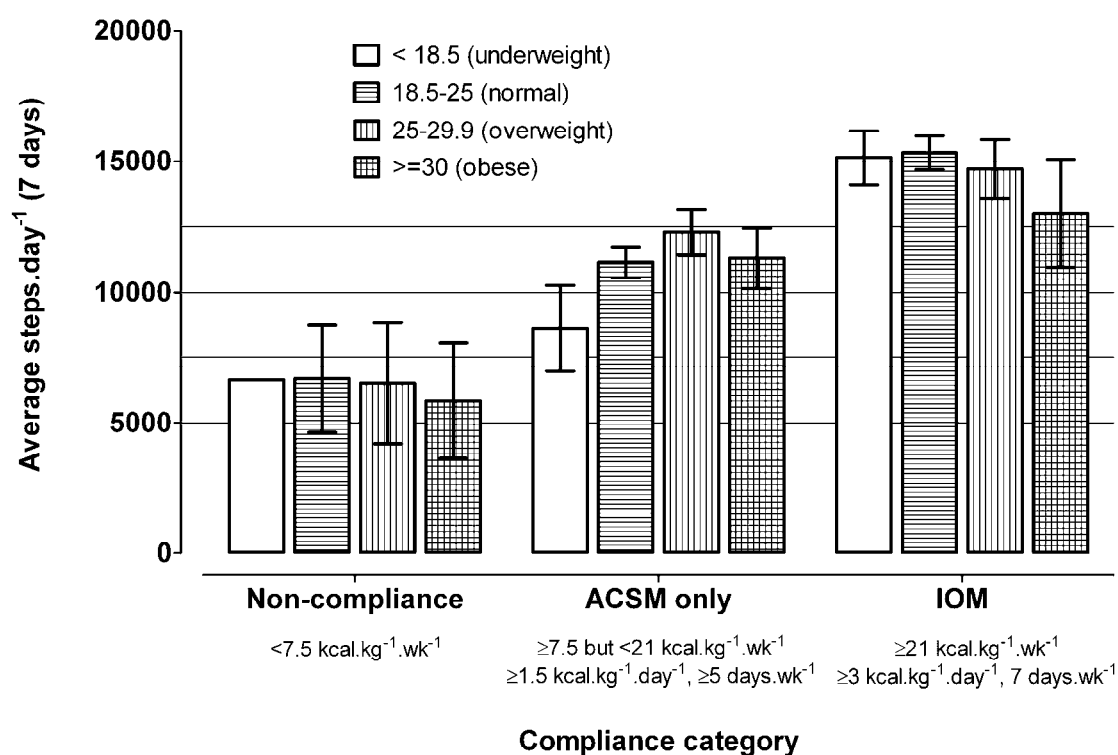


Figure 9.3. Ambulation levels for BMI categories across non-compliance and compliance categories for ACSM and IOM physical activity guidelines in the DHDSS sample. Average steps.day⁻¹ are age-adjusted and weighted to the DHDSS population. The underweight category of the non-compliance category contains only three subjects hence the 95%CI have been omitted.

This is the first analyses that we are aware of that has examined compliance with the ACSM and IOM recommendations in a South African sample using pedometer data. The SADHS conducted in 2003 reports PA levels in a nationally representative sample and suggests that for male and female non-urban Africans the prevalence of inactivity, minimal activity and sufficient activity is 48.0%-63.2%, 22.9%-28% and

14.0%-23.6%, respectively.¹⁵⁶ Furthermore, non-urban African males are reportedly less inactive and more active than females.¹⁵⁶

The SADHS survey utilized the GPAQ which has been reported to display reasonable reliability and concurrent and criterion validity in a South African sample (n=215).¹⁵⁶ However, Thorogood *et al.* using an interview-based questionnaire framed on the IPAQ, found prevalence estimates of 8.0%, 18.7% and 73.4% for sedentary, low active and moderately active categories, respectively in a rural African sample (n=402).⁵⁹⁴ In contrast to the SADHS prevalence estimates, females were more active than males, and reported less sedentary behaviour, although not significantly so ($p=0.275$).⁵⁹⁴

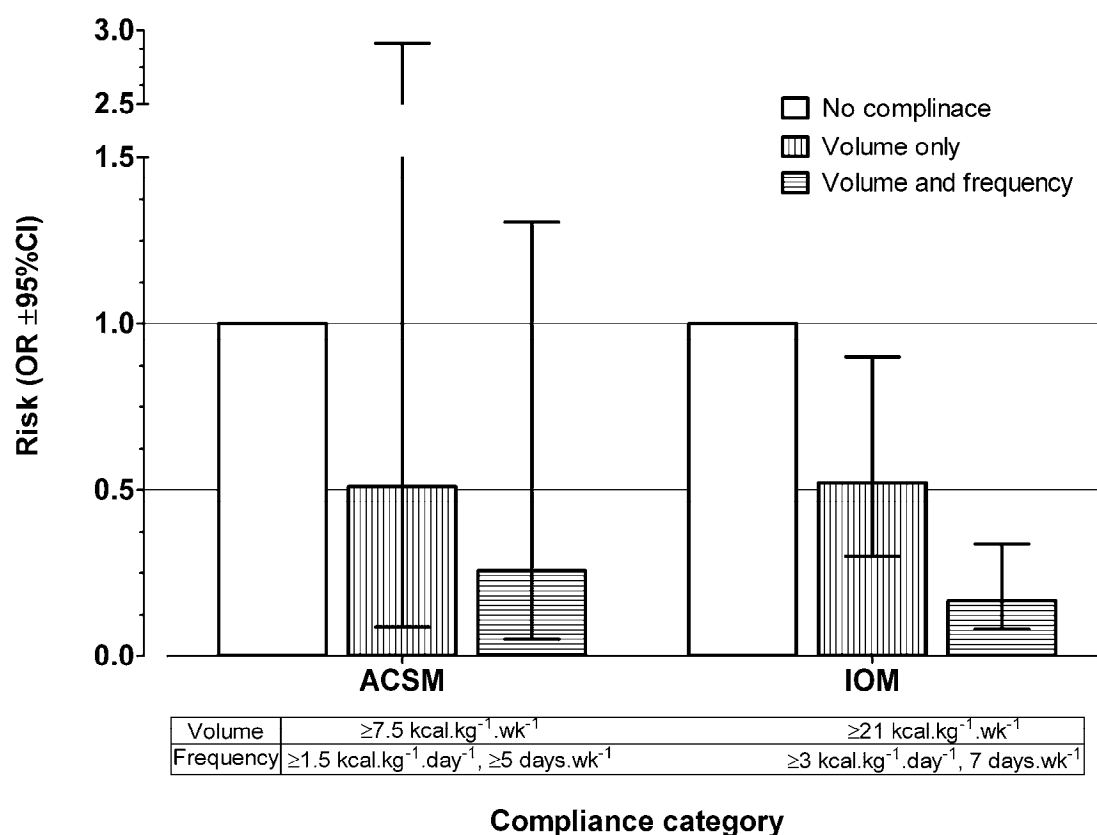


Figure 9.4, Risk of BMI-defined obesity ($\geq 30 \text{ kg.m}^{-2}$) across non-compliance, volume-only and volume and frequency compliance categories for ACSM and IOM physical activity guidelines in the DHDSS sample. Odds ratios are adjusted for age, sex and season and weighted to the DHDSS population.

Importantly, the IPAQ questionnaire was adapted around the understanding that walking, carrying a load, constituted a major portion of the day and excluded questions about leisure because of the lack of leisure-time concept in that population, suggesting that due attention had been paid to construct validity.⁵⁹⁴ Moreover, age-adjusted prevalence estimates for sedentary ($<5\,000$ steps.day⁻¹) and active-very active ($\geq 10\,000$ steps.day⁻¹) categories in a rural African sample ($n=775$), were 8.0% and 66.6%, respectively.¹²⁷ The prevalence estimate reported in the present analysis for compliance equal to and exceeding the ACSM guideline of 92.2% suggests an over-estimation although Davis *et al.* reported an ACSM compliance of 94% and 71% for normal weight and over-weight/obese subjects, respectively in a small seven-day accelerometry trial ($n=31$).¹⁵³ However, the estimate for non-compliance or inactivity of 7.8% in rural Africans is in agreement with other estimates.^{127,594} It is likely that part of the over-estimation of ACSM-IOM compliance was the result of light-moderate AEE data being included in the total AEE. The NL-2000 does not filter out valid light-to-moderate intensity steps, although accuracy does fall off from walking speeds of 67 m.min⁻¹ and below such that fewer light-to-moderate steps would be captured.¹⁴⁷

It is interesting to note that the prevalence for sufficient PA reported by the SADHS using the GPAQ questionnaire¹⁵⁶ and the World Health Survey using the IPAQ questionnaire⁶⁷⁷ was 28.1% - 41.8% and 17.6% - 28.6% for rural males and females, respectively. These nationally representative results indicate a greater discrepancy between our results for ACSM-only compliance and rural females (31.9% - 42.9%) than for rural males (8.1% to 21.8%), raising the possibility of greater under-reporting of physically active behaviour in rural females. Of further note, is that our ACSM-only compliance estimates show a similar pattern to that of Thorogood *et al.* namely females are more active than males.⁵⁹⁴ Another possible explanation for the discrepancies between our results and those reported in the SADHS¹⁵⁶ and the World Health Survey⁶⁷⁷ is that the PA questionnaire probed PA behaviours indicative of ACSM guidelines. First, each PA category (occupational, travel, non-work related and leisure) was preceded by a screening question which excluded all activities <10 min in duration. Second, the questionnaire did not probe certain activity categories sufficiently (yard/household) such that female activities

would most likely be under-reported.¹²⁸ In agreement with Mudd *et al.* we would argue that the SADHS PA questionnaire is suited to examining ACSM guideline compliance from a MET-min.wk⁻¹ perspective but not from an AEE, perspective.⁴³¹ As such, the SADHS PA questionnaire while displaying acceptable reliability and validity coefficients, might be displaying a “floor” effect such that certain health enhancing PA patterns are not being probed.¹²⁸ It would seem possible then that from an AEE perspective, a significant portion of PA behaviours are not being reported in the SADHS results which would otherwise have contributed to the total energy balance. Finally, Mudd *et al.* report an AEE-derived IOM compliance estimate of 27.7% for a North American population, which, as would be expected, is less than our pedometer-derived IOM compliance estimate of 37.2% for a rural African sample, and does suggest that our estimates are reasonable.

In agreement with other studies, individuals who accumulate ≥ 10000 steps.day⁻¹ are more likely to meet ACSM guidelines although meeting this step count guideline does not guarantee meeting the 30 min.day⁻¹ ACSM guidelines.^{285,339,373} Indeed, we have shown that 13.1% of individuals that do not accumulate $\geq 10\,000$ steps on any of the seven monitored days, met the full ACSM guidelines. Furthermore, 49.5% of those individuals that accumulated ≥ 10000 steps on 3 or less days met the ACSM-only guidelines. In contrast, compliance with the IOM guidelines requires much greater ambulation levels such that nearly 75% of those meeting the IOM guidelines accumulated $\geq 10\,000$ steps on 6-7 days with an average of 15 064 steps.day⁻¹. Macfarlane *et al.* had 49 subjects wear an electronic pedometer and a uni-axial accelerometer for seven days and found that accumulating 11 762 steps.day⁻¹ equated to 68.6 min.day⁻¹ of moderate-to-vigorous activity.³⁷³ Similarly, Le Masurier *et al.* found that individuals accumulating more than 10 000 steps accumulated 62 min of moderate PA.³³⁹ However, if the amount of moderate PA accumulated is expressed in bouts of ≥ 5 min or ≥ 10 min, the time spent in moderate PA reduces to 40.8 min and 30.1 min, respectively.³³⁹

The IOM guideline of 420 min.wk⁻¹ addresses issues around weight loss and prevention of weight gain after weight loss, unlike the ACSM guideline of 150 min.wk⁻¹ which addresses risk reduction for all-cause mortality and morbidity.^{257,288} Not

surprisingly then, we found a significantly lower multivariate-adjusted risk of obesity for compliance with the IOM guideline compared with the ACSM guideline. Mudd *et al.* have shown that the low IOM AEE group contains greater percentages of obese individuals compared with the compliant IOM AEE group.⁴³¹ Indeed, we found the non-compliant, ACSM-only and IOM compliant groups consisted of 60.8%, 43.0% and 19.1% of over-weight to obese individuals, respectively. Our results for IOM compliance of 42.4% and 23.2% for normal weight and over-weight/obese subjects, respectively, are in general agreement with Davis *et al.* who reported 26% and 13%, respectively.¹⁵³ Considering that our population is rural and with a greater reliance on subsistence activities,¹²⁸ it is to be expected that we would report higher compliance with IOM guidelines. The females in our sample displayed a four-fold higher weighted prevalence of obesity compared with males (23.6% and 5.7% respectively) and is likely in part the result of the greater compliance of IOM guidelines (1.5-fold) and lower non-compliance prevalence (1.6-fold) in males compared with females.

A number of limitations must be acknowledged. First, the AEE we obtained from the pedometer was derived from an algorithm which sums all activity (light-to-vigorous). However, Mudd *et al.*⁴³¹ obtained their AEE from self-report data where the intensity and duration of the activity were known and thus the AEE they calculated did not contain energy expenditure from light activities. Second, we did not compare our AEE approach to pedometer data against accelerometers. Future studies are required to more fully test the validity of our approach to pedometry data. Third, although we have presented evidence from objective measures of PA to argue that self-report questionnaire data might be under-reporting physically active behaviour and over-reporting sedentary behaviour especially for rural African settings, our assertion needs to be corroborated by the simultaneous use of objective monitoring and self-report of PA

In conclusion, our novel approach to pedometry data collected in a rural African sample has shown congruence with expected ambulatory levels and obesity risk. Importantly, our results appear to provide further evidence that self-report measures within a rural African setting require careful design, to avoid “floor effects” such that important AEE -contributing physical activities are not excluded. Alternatively,

greater use should be made of objective monitoring of PA to corroborate the findings of self-report surveys, albeit in smaller samples.

CHAPTER 10: THESIS SUMMARY AND CONCLUSIONS

10.1. INTRODUCTION

This thesis investigates the implementation of objective measures of physical activity, specifically accelerometers and pedometers, in a rural South African setting. A number of research questions arose during this work and are presented and discussed in each chapter of this thesis. This section summarises the conclusions in each chapter, answers each of these questions and discusses the implications and practical applications of these conclusions.

10.1.1. Chapter 2

Question

What are the sources and distribution of variance and associated reliability over a number of hours and days?

Answer

For the 14-hr period more than 70% of the variance was intra-individual, while intra-individual and inter-individual variance accounted for approximately 40% each for the 4-day period. Total counts, average counts and counts ≥ 1952 were the most reliable measures. Interestingly, residence revealed different hourly patterns such that there was more homogeneity in the rural group than the urban group and because an objective measure was used the greater intra-individual variance is likely due to actual variations in physical activity. Because communities differ in terms of how far they have progressed along the Physical Activity Transition it is important that similar analyses are performed which will likely yield different variance distributions that are in accord with their physical activity behaviours. Coupled with demographic factors such as residence and gender, the number of hours and days required to reliably estimate usual physical activity patterns are likely to differ across communities.

10.1.2. Chapter 3

Question

What is the effect of monitor placement and monitor unit on the variance distribution and associated reliability?

Answer

Accelerometer output did not differ between the hips over the three days and monitor placement contributed no variance to the total variance in accelerometer variables. However, monitor units contributed nearly 2% of the variance in accelerometer variables suggesting that statistical analyses should adjust for monitor unit. The novel finding of this study was a greater within-subject variance for moderate-to-vigorous counts >1951 compared with that from industrialized settings where a larger portion of the counts was accumulated above 1951 counts.min⁻¹. Researchers working in more rural settings where counts are accumulated at lower ranges are cautioned against collapsing moderate and vigorous activity zones into a single variable in order to dilute greater variability from the moderate zone.

10.1.3. Chapter 4

Question

Can a valid subsistence activity index be constructed from subsistence variables?

Answer

Significant linear relationships were found across a subsistence activity index constructed from subsistence variables related to electricity, food preparation, passive transport and water collection. In particular, the accelerometry derived variables revealed increasing activity levels with increasing subsistence levels. The results underscore the importance of NEAT in a rural African setting and the relative ease with which it can be quantified at this point in time. The study highlights the importance of identifying the relevant physical activity domains within a community and constructing appropriate self-report measures or using more objective measures of physical activity.

10.1.4. Chapter 5

Question

What are the implications of accelerometer count distribution and moderate-intensity cut-points in terms of current physical activity guidelines?

Answer

This study shows the effect of different moderate intensity thresholds when evaluating the prevalence of adhering to physical activity guidelines, and the importance of describing accelerometer counts over the full count ranges. Rural

women accrued significantly more activity in the count range 760-1951 accumulated in 1 min or 10 min bouts compared with urban women. Adherence based on bouts ≥ 10 min for counts >1951 results in a 1.4-fold greater adherence for urban women, yet for counts >760 , the adherence is 3.3-fold higher in rural women, this despite rural women accumulating significantly more total counts. These results highlight the accumulation of activity in rural women in a narrow count band which is the result of higher NEAT activities compared with urban women. If the oft-used 1952 cutpoint is used to evaluate adherence to physical activity guidelines, the possibility of misclassifying rural African women as physically inactive is increased.

10.1.5. Chapter 6

Question

How well does a coiled-sprung research-grade pedometer function in a rural setting?

Answer

Using a commonly-used, coiled-sprung research grade pedometer in a rural African setting highlights the relative ease with which ambulatory activity can be accurately quantified. The increased precision revealed significant multivariate-adjusted associations with measures of adiposity and passive transport carried an increased risk of adiposity, adjusting for average steps per day. The study also highlighted the disadvantages of using this particular pedometer in that if participants did not properly fit the pedometer each day it ceased to function and the lack of a multi-day memory function precluded a daily record of step totals. The study provided important data with which to calculate sample size for future studies.

10.1.6. Chapter 7

Question

How well does a multi-day memory, accelerometer-based pedometer function in a rural setting?

Answer

Based on the earlier study, an accelerometer-based pedometer, not affected by absolute vertical positioning requirements or adiposity level, and having a seven-day memory recall for both total steps and activity energy expenditure was used in a

large survey in a rural African setting. The novel study yielded interesting patterns between genders and village residence that would likely not have been detected using self-report measures. The study also revealed the high ambulation levels across age and adiposity levels, and once again underscored the high levels of NEAT through ambulatory activity in this community in transition. The high ambulation levels also questioned whether this community has low levels of physical activity as suggested by self-reported data.

10.1.7. Chapter 8

Question

What are the primary factors (body mass, volume, intensity) contributing to energy expenditure accrued through high ambulation levels in a rural setting?

Answer

The availability of stored activity energy expenditure and step count data and body mass makes possible some disentangling of volume and intensity effects from otherwise limited data. Using the data from Chapter 7, this study uses relatively simple statistical methods to infer intensity and volume effects such that the high ambulation levels measured in a rural setting could be explained to some degree. The study highlights a possible intensity effect for accumulating $\geq 10\,000$ steps on 6-7 days of the week and accumulating an average of $\geq 12\,500$ steps.day⁻¹. These results suggest that the majority of ambulatory NEAT is accumulated as a function of volume, and has implications for physical activity guidelines and interventions.

10.1.8. Chapter 9

Question

Can compliance/non-compliance with physical activity guidelines be inferred using a novel approach to energy expenditure-derived pedometer data?

Answer

Using data from Chapter 7, this study found that the concurrent activity energy expenditure and step count data stored over seven days, made possible the application of an energy-expenditure approach to pedometry data. Importantly, the study confirms that compliance with Institute of Medicine guidelines requires substantially more ambulation than complying with American College of Sports

Medicine guidelines. Interestingly, compliance with the latter guideline does not require accumulation of 10 000 steps of more per day on most days of the week. The study also highlights the stronger association with lower adiposity levels for those complying with full IOM guidelines as opposed to those partially complying with IOM guidelines and complying with ACSM guidelines only. These results confirm that in contrast to IOM guidelines, ACSM guidelines are not primarily aimed at energy balance, but rather all-cause mortality.

10.2. INTERPRETATION AND PRACTICAL APPLICATIONS

Accelerometry

Uni-axial accelerometry has been a method of choice in studies that range from tens to thousands of participants although subsequent generations of tri-axial accelerometers with enhanced features and capabilities are now available. Not only can the volume of movement be quantified, but also the frequency and intensity of movement. The technology is reliable and robust and the methodologies for data collection and analysis have evolved such that the procedures and data analysis software are generally available to researchers. In addition, the accelerometer output, if properly standardised, is readily comparable across cultural, language, geographical and socio-economic settings. Despite the relative ease with which this technology can be implemented, certain aspects do require validation within the context the technology is to be used in.

The sources of variance will determine the level of reliability of a measure, and depending on the level of reliability required, influence the minimum amount of monitoring periods required. Not only does this have time and cost implications, but also affects the statistical power of a study. To investigate sources of variance requires that repeated measures are made, and it is this type of data that is used to estimate measurement error and thus de-attenuate a number of statistical coefficients. Chapter 2 showed the variance distribution in a particular setting and that variance distributions described in different settings should not be assumed to apply generally. The caution with which researchers should approach the generalizability of variance distribution was also highlighted in Chapter 3. Taken together, these chapters suggest that prior to the implementation of large-scale

accelerometry, especially in more rural areas, smaller repeated measures studies should be conducted to determine the amount of monitoring required and measurement error coefficients which can be applied in later analyses to provide more precise relationships between physical activity and health.

The Physical Activity Transition model predicts that as communities progress in terms of economic and structural development, so there is a shift in physical activity patterns. More industrialised settings display low total physical activity patterns, with most of the activity accrued through leisure-time activity. In contrast, communities situated earlier in the transition, display greater reliance on subsistence activities which are accumulated over long periods at low-to-moderate intensities. The uncritical acceptance of accelerometer intensity thresholds developed in more urbanised setting where NEAT is low but leisure-time physical activity is higher, misclassifies individuals from more rural settings as physically inactive. The results from Chapters 4 and 5 show the necessity of acknowledging the importance and preponderance of NEAT in rural communities and using appropriate accelerometer intensity thresholds so that meaningful comparisons can be made between settings and across time as the physical activity patterns change. Moreover, the relative ease and accuracy with which accelerometry measures NEAT in a free-living setting suggests that greater use should be made of this technology when studying physical activity changes over time or across settings as changes to the environment alter the contribution of NEAT to overall energy expenditure.

Pedometry

The plethora of studies using pedometers in randomized trials to large surveys, and the ease of comparison across diverse settings, attests to the robustness of this particular movement monitoring method. In addition, in comparison with accelerometry, pedometry is relatively inexpensive and the data relatively straightforward to record, analyze and interpret. Considering the large proportion of NEAT that is accrued through active transport (walking) in large segments of the South African population, and the growing public health message in South Africa to reduce passive transport where possible, suggests that greater use be made of pedometers in terms of health promotion and health research.

However, there is a dearth of studies using pedometry in Africa, and certainly no studies in rural South African settings. Consequently, the data generated from Chapter 6 provides not only the first glimpse of more accurately measured physical activity levels in a rural setting, but will also serve to inform future studies in South Africa. The larger survey that followed in Chapter 7 is the largest study to date in any South African setting using an objective measure of physical activity and highlights the relative ease with which accurate ambulatory data can be collected in large samples and the interesting, novel patterns and associations that have emerged. The results from Chapters 8 and 9 suggest that pedometry data can be used in novel ways to evaluate to a greater degree the compliance or non-compliance with physical activity guidelines. Moreover, the results suggest that pedometry is relatively sensitive to differences in ambulation resulting from cultural and environmental influences. As such pedometry is a useful adjunct to accelerometry when investigating changes in physical activity volume due to the Physical Activity Transition.

Figure 10.1 summarizes the differences between physical activity/inactivity and sedentarism and how this may be estimated using accelerometers and pedometers and some useful accelerometer and pedometer indices are suggested. The greater use of objective monitoring will require some level of standardization of procedures and output such that data are comparable across time and between settings and as such this schema represents the basic criteria which researchers should attempt to adhere to.

10.3. FUTURE RESEARCH

The studies in Chapters 2 to 9 were the first studies from a local and national setting reporting accelerometer and pedometer data. As such the questions asked were relatively simple and addressed certain fundamental aspects. Further analysis using larger sample sizes for both accelerometer and pedometer data should provide more definitive data regarding the reliability of these measures, in particular for accelerometry counts accumulated in low-to-moderate intensities. While health data relating to adiposity to accelerometry and pedometry output has been reported in this thesis, the relationship between objective measures of physical activity and other

health measures such as blood pressure, blood glucose and blood lipid variables should be examined in this rural setting. Future analysis should also focus on sedentary accelerometry measures, in particular bouts of sedentary time accumulated in rural settings and the relation to health variables. There is also an urgent need to build in an objective measurement arm to national physical activity surveillance initiatives. Moreover, the construction of better self-report physical measures that will compliment the data obtained from objective measures, particularly in rural settings where the Physical Activity Transition is rapidly advancing, is imperative.

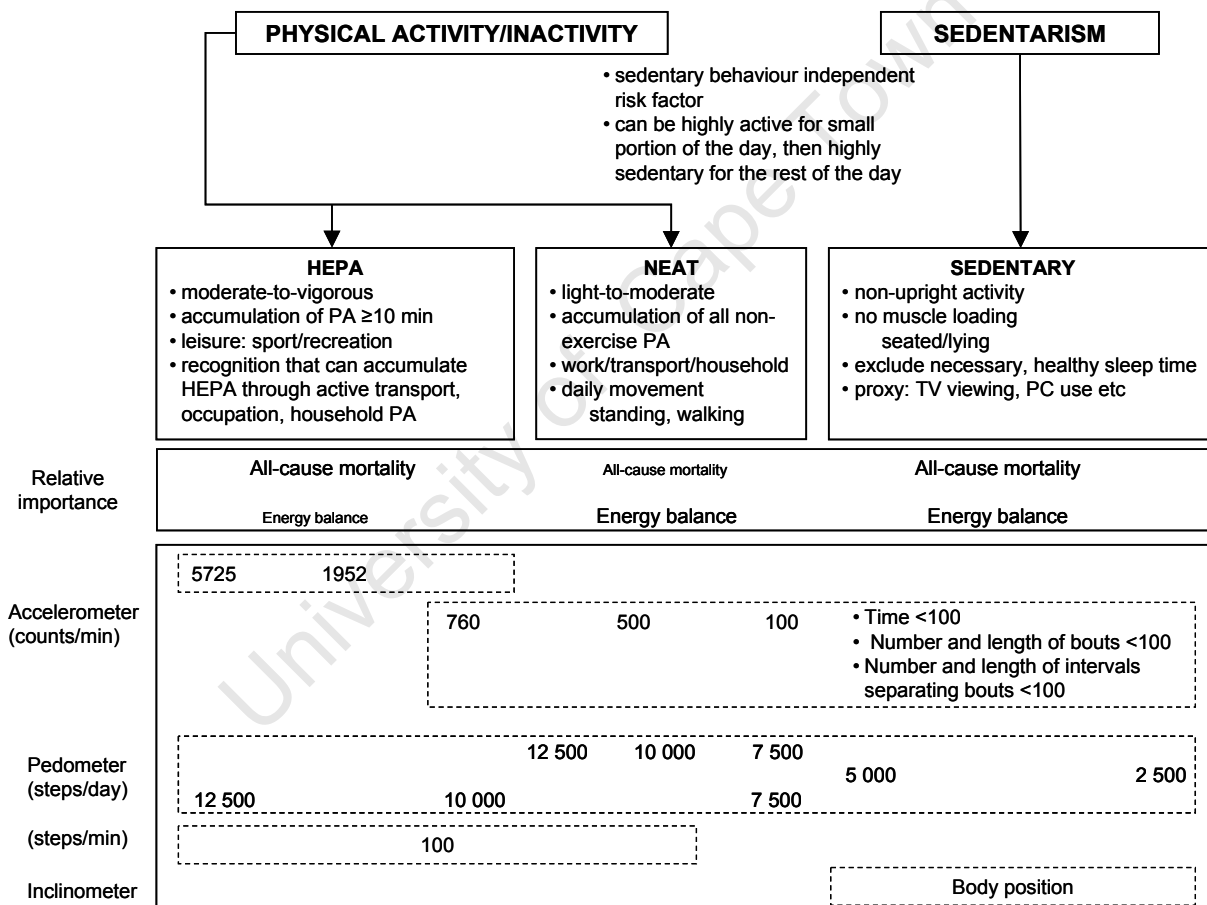


Figure 10.1. Measuring physical activity and inactivity with objective measures. HEPA = Health Enhancing Physical Activity, NEAT = Non-exercise Activity Thermogenesis, PA = Physical Activity.

10.4. CLOSING STATEMENT

The findings of the studies in Chapters 2 to 9 can be interpreted to suggest that accelerometry and pedometry are robust and valid objective measures of physical

activity in a rural South African setting where NEAT activities predominate. There is a growing body of literature which supports the greater use of objective measures of physical activity such that the relationship between physical activity/inactivity and sedentarism and health measures are more precisely described. Furthermore, repeated measures of physical activity using objective methodologies will allow the generation of error correction coefficients such that the relationship between subjective and objective physical activity measures and health variables can be strengthened, particularly for light-to-moderate intensity activities which are difficult to quantify with subjective measures of physical activity. There is also a realization that self-report and objective measures of physical activity offer different perspectives on a fundamental human behaviour. The former provides essential contextual, qualitative data, the latter substantial quantitative data. The regular collection of physical activity data using subjective and objective measures should provide useful information as community's progress through the Physical Activity Transition and allow appropriate interventions and health promotion campaigns and messages to be implemented. At this stage the results from national surveillance instruments should be interpreted cautiously until additional data from studies incorporating objective measures of physical activity are available.

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- University of Cape Town

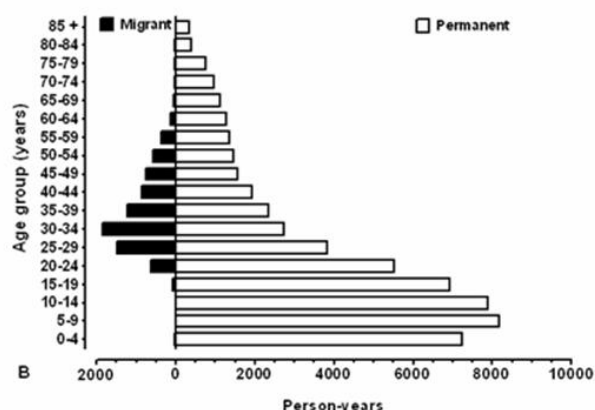
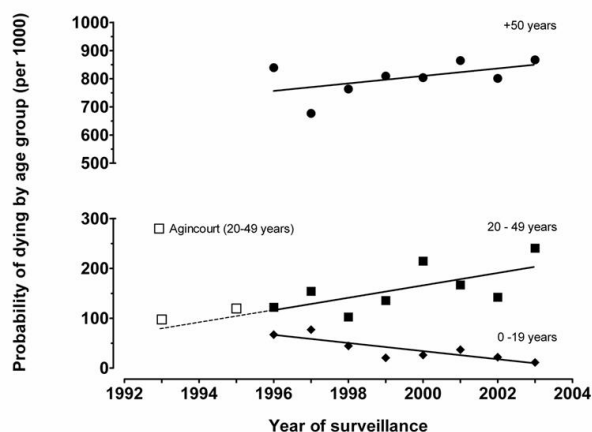
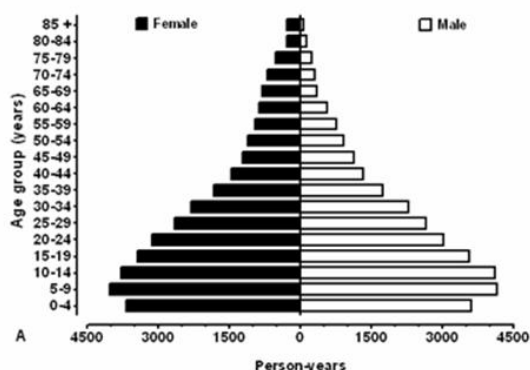
- central region of the Limpopo Province, South Africa
- ≈40 km northeast of Polokwane
- ≈15 km from the Turfloop Campus of the University of Limpopo



- Established in 1995 with the assistance of the Witwatersrand University Agincourt Demographic and Health Surveillance System site (ADHSS; <http://www.agincourt.co.za/>)
- The first phase of data collection in 1996 with further yearly revisits (1996 to present)

- DHDSS is part of the INDEPTH Network of demographic surveillance sites located in Africa, Asia and Central America (<http://www.indepth-network.org>).

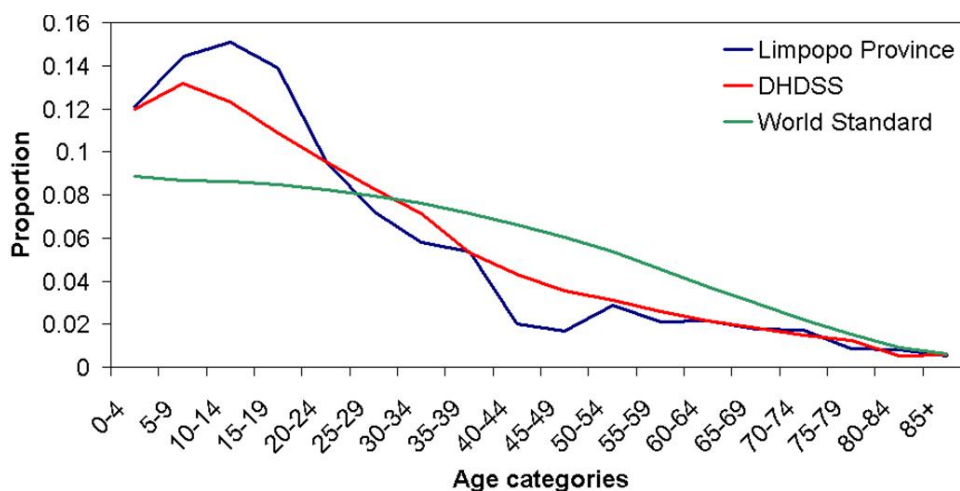
Demography:



Mortality estimates across time for three age categories in the DHDSS (1996–2003). The ADHSS data (%) is shown for comparative purposes and was not included in the regression analysis. Slopes (95% CI) for each DHDSS age group are as follows: 0–19 years: 28.1/1000/year (213.1 to 23.2); 20–49 years: +12.4/1000/year (22.0 to +26.9); 50+ years: +13.3/1000/year (28.2 to +34.7). Reproduced from Cook *et al.*¹³¹

Age-sex profile of the DHDSS population, in person-years observed from 1996 to 2003. Reproduced from Cook *et al.*¹³¹

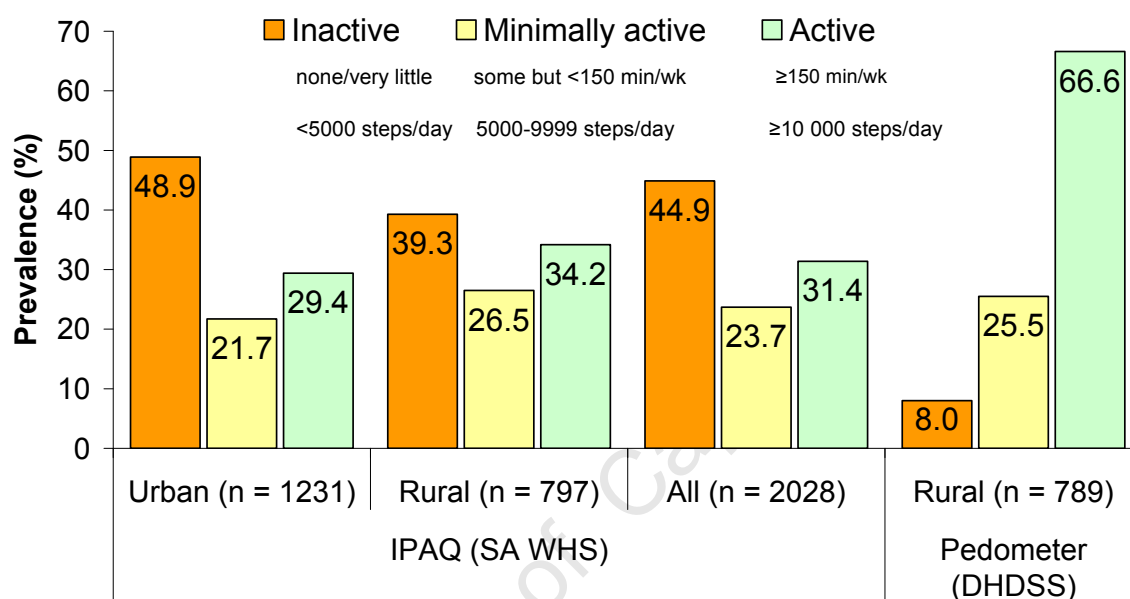
AGE STRUCTURE OF DHDSS, LIMPOPO PROVINCE AND WORLD STANDARD



APPENDIX 2:

COMPARISON OF PREVALENCES: SUBJECTIVE VERSUS OBJECTIVE MEASURES

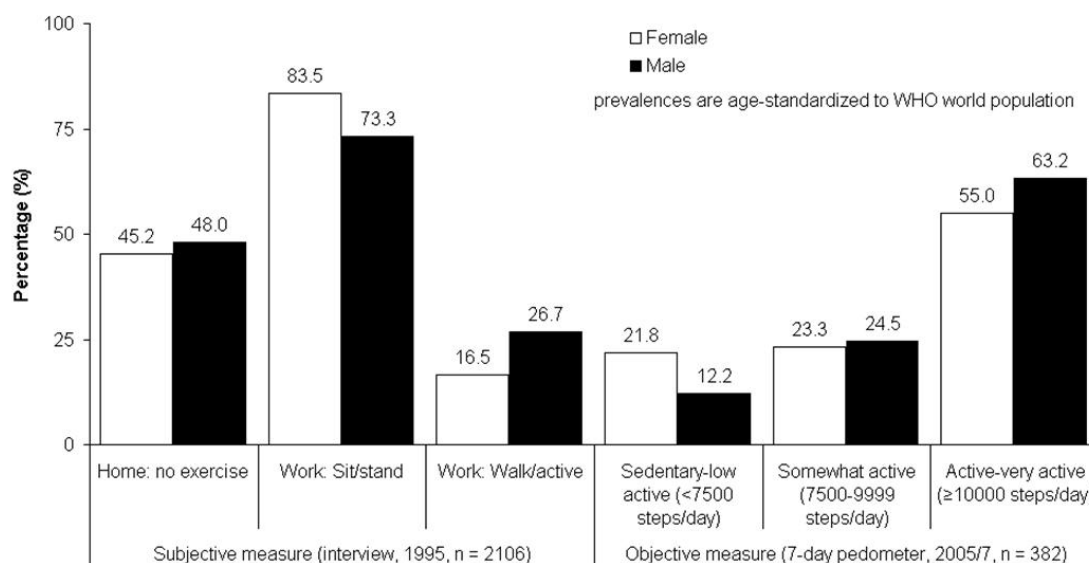
SOUTH AFRICAN PREVALENCES FOR PHYSICAL ACTIVITY/INACTIVITY (WHS, 2002-2003; DHDSS, 2005-2007)



Demographic and Measurement type category

Drawn from data in Cook *et al.*¹²⁷ and WHO⁶⁷⁷

Physical activity/inactivity prevalences by subjective and objective measures in rural Africans (≥ 30 years)

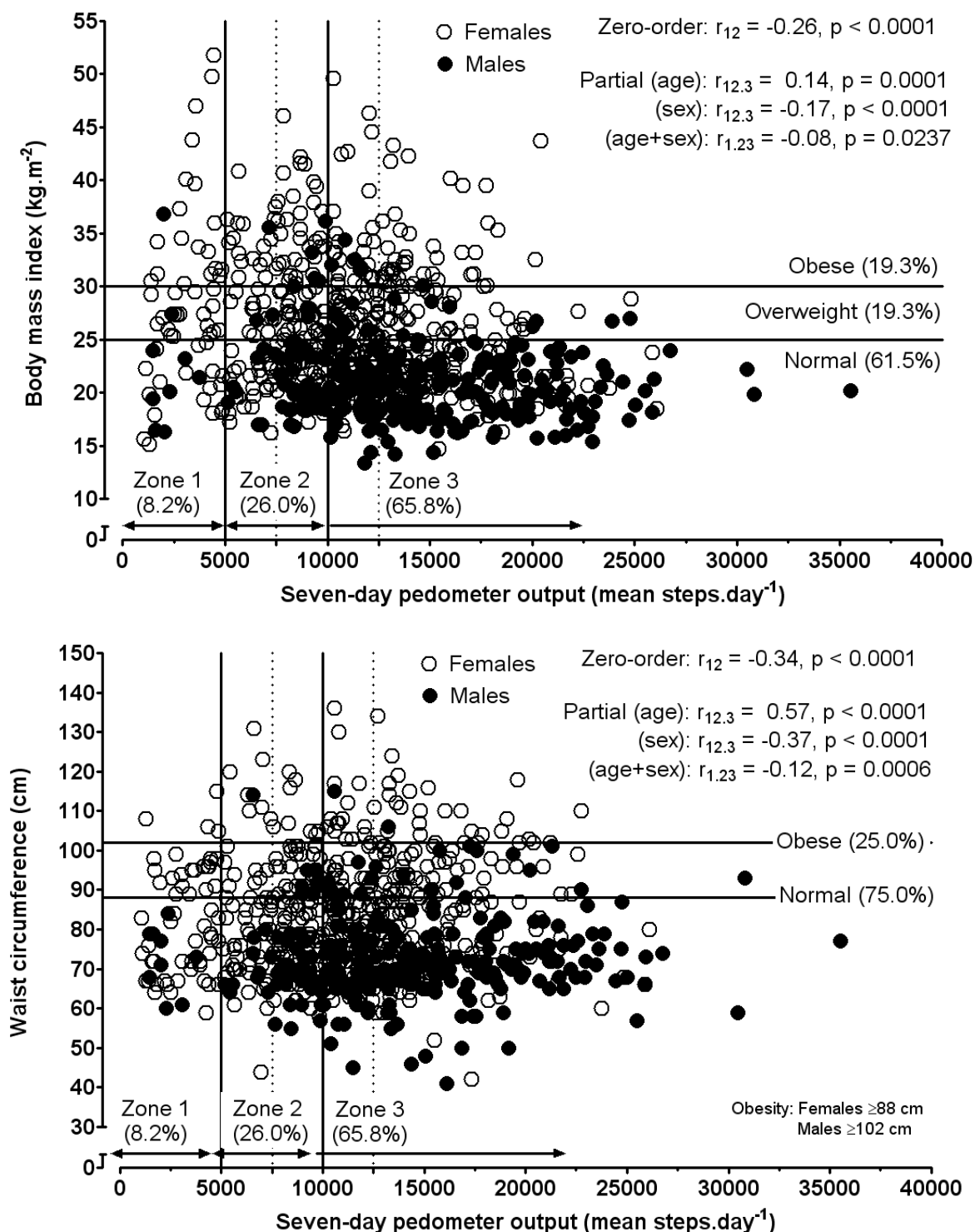


Physical activity category by measurement type

Drawn from data in Alberts *et al.*¹⁵ and Cook *et al.*¹²⁷

APPENDIX 3:

SCATTERPLOTS FOR STEPS PER DAY VERSUS ADIPOSITY MEASURES IN 789 RURAL, ADOLESCENT AND ADULT BLACK SOUTH AFRICANS.



Relationship between steps per day and adiposity measures in 789 rural Africans. Drawn from data in Cook *et al.*¹²⁷

APPENDIX 4:

EQUATIONS USED TO ESTIMATE MAXIMUM OXYGEN UPTAKE

Maximum oxygen uptake (VO_{2max}) is estimated from the stage oxygen uptake (VO_2) and measured heart rate (HR) from the last completed stage.³⁸²

Stage 1 VO_2 : $16.287 \text{ mlO}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$

Stage 2 VO_2 : $24.910 \text{ mlO}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$

Stage 3 VO_2 : $33.533 \text{ mlO}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$

Uncorrected $VO_{2max} (\text{l} \cdot \text{min}^{-1}) = V'O_{2max} = \text{Stage } VO_2 / \%VO_{2max}$

where $\%VO_{2max} = [0.769 \times \text{Stage HR (beats} \cdot \text{min}^{-1})] - 48.5$ (male)

$\%VO_{2max} = [0.667 \times \text{Stage HR (beats} \cdot \text{min}^{-1})] - 42.0$ (female)

and

$VO_{2max} (\text{l} \cdot \text{min}^{-1}) = (0.348 \times V'O_{2max}) - [0.035 \times \text{age (years)}] + 3.011$ (male)

$VO_{2max} (\text{l} \cdot \text{min}^{-1}) = [0.302 \times V'O_{2max}] - [0.019 \times \text{age (years)}] + 1.593$ (male)

EQUATIONS USED TO ESTIMATE PERCENTAGE BODY FAT

Sum of four skinfolds (SSKF, mm) = Triceps + Biceps + Subscapular + Suprailiac

Female body density ($\text{g} \cdot \text{cm}^{-3}$):¹⁸⁰

Age ≥ 17 yr but < 20 yr Body density = $1.1549 - 0.0678 \times \log_{10}(\text{SSKF})$

Age ≥ 20 yr but < 30 yr Body density = $1.1599 - 0.0717 \times \log_{10}(\text{SSKF})$

Age ≥ 30 yr but < 40 yr Body density = $1.1423 - 0.0632 \times \log_{10}(\text{SSKF})$

Age ≥ 40 yr but < 50 yr Body density = $1.1333 - 0.0612 \times \log_{10}(\text{SSKF})$
 Age ≥ 50 yr Body density = $1.1339 - 0.0645 \times \log_{10}(\text{SSKF})$

Percentage body fat (PBF)⁵⁴⁹ = $4.95/\text{Body density} - 4.5 \times 100$

ACCELEROMETER AND PEDOMETER THRESHOLDS USED TO DIFFERENTIATE PHYSICAL ACTIVITY INTENSITY AND VOLUME LEVELS

ACCELEROMETER INTENSITY THRESHOLDS				
Intensity		Chapter 2+3	Chapter 4	Chapter 5
		Counts.min ⁻¹		
Sedentary	<3 METs	0-499	0	0 – 99
Light			1 – 573	100 – 759
Moderate-1	3 -5.9 METs	500 – 1591	574 – 4944	760 – 1951
Moderate-2		1592 -5724		1952 – 5724
Vigorous	≥ 6 METs	≥ 5725	≥ 4945	≥ 5725
		Matthews <i>et al.</i> ³⁹⁰	Swartz <i>et al.</i> ⁵⁸¹	Matthews ³⁸⁸
1 MET ≈ 3.5 ml O ₂ .kg ⁻¹ .min ⁻¹ ≈ 1 kcal.kg ⁻¹ .hr ⁻¹				

PEDOMETER STEP VOLUME THRESHOLDS	
Volume	Chapter 6-9
	Steps.day ⁻¹
Sedentary	<5000
Low active	5000 – 7499
Somewhat active	7500 – 9999
Active	10 000 – 12 4999
Very active	$\geq 12\,500$
Tudor-Locke <i>et al.</i> ^{618,622}	

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LIST OF ABBREVIATIONS

ACSM	American College of Sports Medicine
AEE	Activity Energy Expenditure
BMI	Body Mass Index
CDC	Centres for Disease Control and Prevention
CDL	Chronic Diseases of Lifestyle
CVD	Cardiovascular Disease
DALY	Disability Adjusted Life Years
DHDSS	Dikgale Health and Demographic Surveillance System site
DLW	Doubly-Labelled Water
DME	Developing Market Economies
EE	Energy Expenditure
EME	Established Market Economies
GPAQ	Global Physical Activity Questionnaire
HDL-C	High Density Lipoprotein Cholesterol
HEPA	Health-Enhancing Physical Activity
HR	Heart Rate
ICC	Intraclass Correlation Coefficient
IOM	Institute of Medicine
IPAQ	International Physical Activity Questionnaire
LDL-C	Low Density Lipoprotein Cholesterol
LGT	Light
LTPA	Leisure Time Physical Activity
MET	Metabolic Equivalent
MOD	Moderate
MVPA	Moderate-to-Vigorous Physical Activity
NEAT	Non-Exercise Activity Thermogenesis
OPA	Occupational Physical Activity
PA	Physical Activity
PAQ	Physical Activity Questionnaires
PBF	Percentage Body Fat

PF	Physical Fitness
PI	Physical Inactivity
SADHS	South African Demographic and Health Survey
SAI	Subsistence Activity Index
SED	Sedentary
SSA	Sub-Saharan Africa
SSKF	Sum of Skinfolds
TC	Total Counts
T-C	Total Cholesterol
TEE	Total Energy Expenditure
TG	Triglyceride
VG	Vigorous
VLDL	Very Low Density Lipoprotein
VO _{2max}	Maximum Oxygen Uptake
WC	Waist Circumference